ELECTRICAL ENGINEERING

JULY 1961
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THE COVER: A microminiature integrated circuit binary full adder which uses as its active and passive elements unipolar field-effect transistors. A binary full adder is a computer circuit which adds three binary numbers, X, Y, and a carry C from a previous stage producing two outputs, one for the sum and one for the carry which is fed to the next stage. Each of these binary numbers may be a 0 or a 1, the 0 corresponding to the pinch-off voltage and the 1 near zero bias. The device utilizes direct coupled unipolar transistor logic involving both *p*- and *n*-type transistors in a complementary symmetry circuit train. The only passive elements are resistors in the form of self-biased unipolar transistors. The adder is fabricated of silicon and mounted on a micromodule wafer 0.031 by 0.031 inch in cross section. (Article begins on p. 488.)

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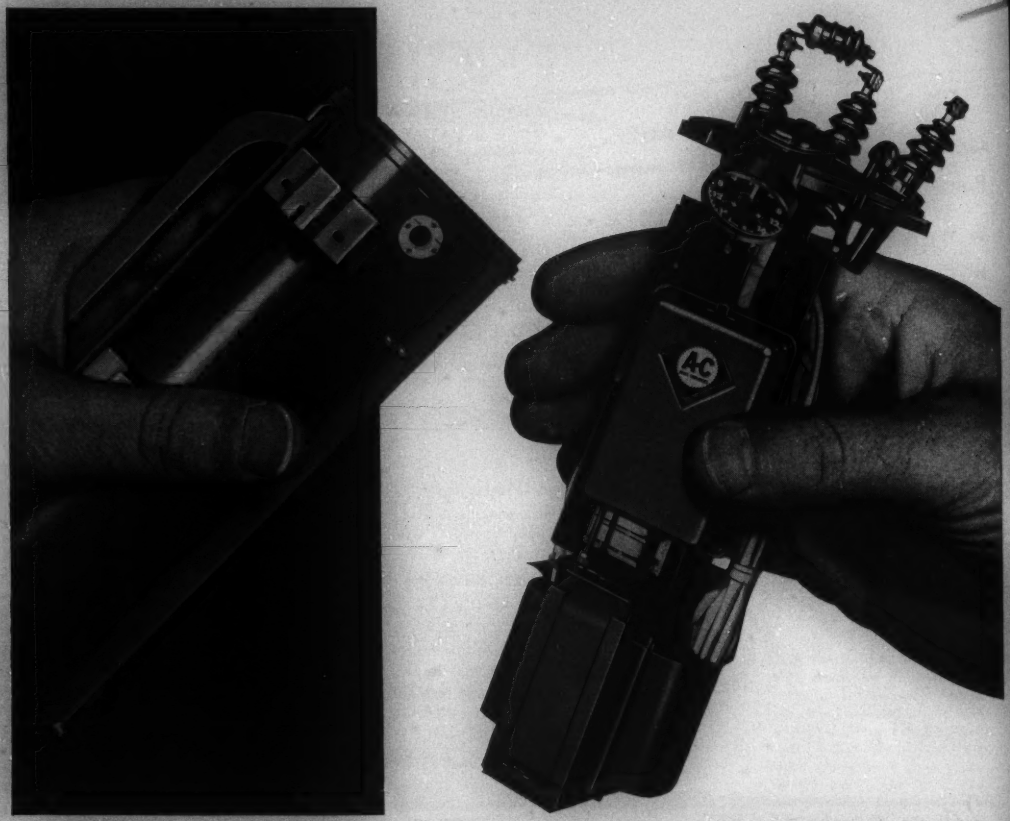

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8. **RESTORING SERVICE** Is the fuse easily and economically restored to service after operating? Fuses that require elaborate replacement components to keep them in service are not only costly, but burdensome to both supply and operating personnel. A simple, inexpensive fuse kit is all that's needed to restore service with Southern States power fuses.

9. **SELF-LOCKING HINGE** When the fuse operates, are the fuse holder and fuse mounting locked together? For safety reasons and to avoid possible damage to nearby equipment, Southern States fuses are equipped with self-locking hinges.

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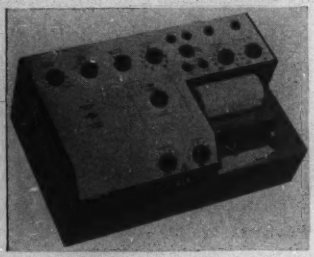

chopper. The recorder operates as a null-balancing electromechanical servo with six linear or logarithmic recording ranges of from 10 to 75 db. Major applications will be found in missile component testing for reliability in noise and vibration, commercial product noise and vibration control, and in calibrating transducers and electronic devices. *B & K Instruments, Inc., 3044 W. 106th St., Cleveland 11, Ohio.*

Epoxy Solder . .

A silver conductive epoxy with resistance closely approaching metals, or between 0.01 and 0.001 ohms–centimeters, has the dual advantage over solder or brazing in that it can be applied at low temperatures for heat-sensitive components and contains no flux or residue to contaminate the parts. Ideal for field repair work, particularly on crowded printed circuits, the epoxy is available in two paste forms curing at 125 C and room temperature. *Epoxy Products, Inc., 137 Coit St., Irvington, N. J.*

Oscilloscope Cart . . .

Type *200*-Series Scope-Mobiles provide a convenient, mobile support for Tektronix oscilloscopes and auxiliary equipment. Featuring an easily-adjustable tray, they can be tilt-locked in any one of nine positions. Available in two models, the *201* has a tray width of 10½ inches to accommodate medium-size oscilloscopes, while the *202* has a tray width of 14 inches to accommodate large units. *Tektronix, Inc., P. O. Box 500, Beaverton, Ore.*

Transformer Tester . . .

Type *GCT-1* Uniload transformer tester was designed to test instrument transformers within 34 ranges of from 5 to 6,000 amperes. As a complete testing facility offering convenience and safety, the equipment contains a heavy-duty current loading transformer, a precision multirange current transformer standard, built-in ASA standard burdens, and a panel-mounted comparator for reading ratio error and phase angle directly from dials. *Knopp, Inc., 1307 66th St., Oakland 8, Calif.*

Rail Car Control . . .

Under development for the past 3 years, this transistorized control for rapid transit and commuter-type rail cars offers increased reliability, reduced maintenance down time, and contains one-third fewer moving parts. Key feature of the unit is extensive application of static components in place of interlock and relay contacts in the control circuits. Components are mounted on plug-in assemblies to make insertion foolproof. *General Electric Co., Schenectady 5, N. Y.*

New Transformer Line . . .

Utilizing a lightweight design which allows a big boost in kva pole mounting capabilities, these new transformers in ratings of 250, 333, and 500 kva represent weight savings for each of 50%, loss reductions of 32% for the higher kva rated unit and 20% for the two lower rated ones, and a 12% higher kva operation without sacrificing service life. *Kuhlman Electric Co., Birmingham, Mich.*

Portable Drawing Instrument . . .

The Polyangle provides complete drafting facilities anywhere for accurate field sketching or drawing to scale, yet it is pocket size when folded in its carrying case. When attached to the

sides of a pad, the main scale slides to provide parallel horizontal lines, while the spring-loaded angle arm can be snapped into increment positions of from 30 to 150 degrees above or below the horizontal. *Country Engineering, Inc., 20 Blueberry Lane, Darien, Conn.*

Miniature Hearing Aid . . .

This transistor hearing aid is so small that microscopes are required in the assembly of its miniaturized parts. Weighing only ⅓ ounce with battery, the instrument can be worn with almost complete unawareness on the part of the user due to the absence of bulk and weight. Capable of being modified to attenuate high or low frequencies, the Signet features a separate on–off switch that will not disturb a preset volume control adjustment. *Zenith Radio Corp., 6001 W. Dickens Ave., Chicago 39, Ill.*

Positive Relay Operation . . .

Aiming for an increase in relay reliability by greatly increasing initial contact pressure, MagTrak assures positive contact even when voltage is low and contact points have become contaminated with surface film. This is achieved by addition of a soft iron bead on the moving pointer and the addition of a permanent bar magnet assembly on each adjustable index arm. When the pointer reaches the control point, the bar magnet pulls in the pointer and moving contact against the flexible arm contact with a rapid snap-wipe action. *Daystrom, Inc., Weston Instruments Div., Newark, N. J.*

(Continued on page 26A)

Business Trends...

THERMOELECTRIC refrigeration, heating, and power generation will become a booming industry by 1965 with annual sales reaching over $425 million. By 1970, the annual sales will probably reach $3 billion. This prediction was made by Dr. R. A. Bernoff, who is director of research, Materials Electronic Products Co., Trenton, N.J.

• • •

MORE THAN $9 million in contracts have been awarded by the Aeronautical Systems Division of the USAF Systems Command, Dayton, Ohio, to the GPL Division of General Precision Inc. These will cover Doppler radar systems for late-type military aircraft.

• • •

A STUDY to investigate various methods of manned transportation between the earth and the moon has been assigned to the Martin Co. by the National Aeronautics and Space Administration (NASA). Symbolic of the space agency's program for the next 10 years, the contract is for the study of launch vehicle systems for lunar exploration beyond the initial Project Apollo flight.

• • •

GENERAL Atomic Division of General Dynamics Corp. has received a contract from the Rome, N. Y., Air Development Center for research into the production of very-high-frequency alternating current by direct conversion of heat into electricity. The program will include the study of conditions under which the cesium cell produces a-c at frequencies of 50 mc or higher.

• • •

THE International Temperature Scale was revised at the 11th General Conference on Weights and Measures in Paris last October. No values of temperature have changed but the triple point of water (0.01 C) has replaced the ice point as one of the six defining points on the scale. Others are the oxygen point (—182.97 C), the steam point (100.0 C), sulfur point (444.6 C), and the freezing points of silver and gold, 960.5 C and 1,063 C, respectively.

• • •

BETWEEN 1954 and 1958, expenditures for research and development in colleges increased from $410 million to $736 million. The scientists and engineers engaged in this research were in the life sciences, 47%; physical sciences, 26%; engineering sciences, 17%; and social sciences, 10%.

ESTABLISHMENT of the first transistor manufacturing company in India was announced by the Raytheon Co. Semiconductors Private, Ltd. is located in Poona, India, and it is planned to produce there transistors and diodes by the end of 1961.

• • •

CHAIRMAN of the Atomic Energy Commission G. T. Seaborg announced that 175 grants totaling $1.950 million have been awarded to 165 educational institutions for purchase of laboratory equipment to expand their curricula in the life and physical sciences and engineering related to nuclear energy.

• • •

TWO GRANTS, totaling $62,000, for the experimental development of a system to produce tape-recorded books for the blind were announced by the Council on Library Resources, Inc. Should the proposed system be feasible, the cost of providing recordings for the blind will be reduced as well as the cost of storing and handling; "readings" will be easier, and the recordings will be better and more durable.

• • •

THE Electronics Industries Association has announced that the factory sales of television picture tubes has increased from $14,395 million to $18,771 million in March 1961 over the previous month. Receiving tubes showed an increase of over $8 million for the same period.

• • •

A PROPOSED set of more precise technical definitions for English-speaking communication engineers from several countries was presented at the Fifth National Symposium on Global Communications. H. H. Smith of ITT Communications Systems, Inc., Paramus, N.J., said that the technical language of English-speaking communication engineers working on transmission systems has developed independently on both sides of the Atlantic for more than 30 years and that often interchanged terms and methods were unfamiliar or misunderstood.

• • •

THE Collins Radio Co. has been awarded $3.3 million in contracts for the purchase of airborne distance measuring equipment (DME) by seven airlines, aircraft owners, and an airframe manufacturer. Eastern, Delta, Northeast, Pacific Southwest, Pan American, Trans World, and United are the seven carriers which have placed orders for DME to be used aboard jet airliners.

What Are Microsystems?

H. W. HENKELS
MEMBER AIEE

The complexity of modern electronic systems has brought about urgent needs for increased reliability and major reductions in size and weight. Microsystems present solutions to these requirements. Beyond providing answers to the immediate problems, microsystems will revolutionize systems engineering and manufacturing design procedures and tend to encourage standardization of basic subsystems.

WITHIN the past few years, greatly increased emphasis has been placed upon the design of electronic systems incorporating major improvements in reliability and decreases in size and weight. The pressure for such improvements has come from the enormous complexity of modern systems in both industrial and military applications. For examples, the electronic components in the large digital computers and the proposed *B-70* aircraft system number in the hundreds of thousands. It is a tribute to the intensive efforts on reliability test programs within both the components and systems industries that such complexes operate at all.

As systems requirements have advanced, the state of the art of active-device manufacture has kept pace with a succession of new components as indicated, since the advent of the transistor, by type names such as point-contact, alloyed, base-diffused, surface barrier, double-diffused mesa, and, quite recently, epitaxial and planar-diffused. Similar advances have been made in the manufacture of passive components of increased stability and precise temperature coefficients, in both conventional and thin-film structures. To meet the reliability, size, and weight requirements for future systems, attention has turned to the integration or aggregation of both active and passive parts in functional subsystems, generally indivisible by the user. The term "parts" is employed in both the sense of distinguishable or separate sections and in the sense of segments or elements of a continuous whole. Such assembly of parts has decreased weight and size of the resulting subsystem by consolidation of support members and elimination of empty spaces in the assembly.

The distinguishing and common characteristic of all these subsystems is their smallness; hence the generic term "microsystems."

A special article recommended for publication by the AIEE Solid State Devices Committee.

H. W. Henkels is manager, advanced development engineering, Semiconductor Department, Westinghouse Electric Corporation, Youngwood, Pa.

This special issue of *Electrical Engineering* is devoted to a review of the needs for microsystems and a presentation of a variety of approaches to their construction and application in both military and industrial equipments.

In brief, microsystems range from those using discrete but miniaturized active components and thin-film passive components (where possible), to those employing hardly distinguishable active and passive regions within single semiconductor structures. An arbitrary division into three basic types of microsystems is possible. The types are: (1) Those in which distinct active and passive components in conventional but miniaturized forms are employed; (2) Those in which distinct active and passive components are used, but one or the other or both of these are in novel forms (for example, thin-film resistors or transistor structures in unique encapsulations); and (3) Those in which distinct active and passive components are absent, the functions being performed in single semiconductor structures. The large scope of microsystems encompasses the activities of many segments of the electronics industry, including manufacturers primarily interested in systems assembly (types 1 and 2); those involved in passive component manufacture (type 2), and those in the transistor business (types 2 and 3). The many attacks result not only from local variations in processing techniques but, more important, from different appraisals or rather complex problems of predicted design flexibility and reliability, manufacturing yields, and market acceptance. The same factors influence the complexity of the subsystems produced and sold as separate microsystems entities.

From the users' standpoint, the introduction of microsystems will revolutionize systems engineering and manufacturing design procedures, parts inventory, stores locations, and field servicing methods. The changes will come basically from the reduction in flexibility occasioned by the incorporation of larger and more complex subsystems of complete systems within microsystems, the internal constituents of which are inaccessible to the user.

While at first glance the reduction in flexibility may seem to make more difficult the optimum design of any system, the benefits that will accrue in standardization of parts, these superior by reason of standardization and volume production, will far outweigh the deficiencies as far as engineering design is concerned.

With microsystem designs established, the problems of parts inventory, stores locations, and field servicing are certainly drastically reduced. The microsystem revolution will certainly have a large effect upon our domestic economy and our defense position.

The Need for Microsystems

H. V. NOBLE

There has been an ever-increasing need for smaller and smaller, yet more and more reliable electronic equipment and components. In this article, some of the important aspects of the evolution of microsystems are considered.

SINCE the beginning of World War II, there has been increasing pressure on the part of the military to make electronic equipment smaller and smaller. There were perhaps two major reasons for the trend; the first being the need to put more and more capability in essentially the same size weapons and weapon carriers and the second, the ability of American industry generally to fulfill this need. However, along with the decrease in size there came a demand for an increase in performance. Hence, the equipment manufacturer was doubly pressed.

The needs for miniaturization were partially met first by the miniature tube, then by the subminiature tube, and finally by the transistor. The pressure for both size reduction and increased performance decreased—and then eliminated entirely—the safety factors conscientious engineers normally incorporated in their designs. This practice, as was to be expected, brought on a rash of unreliability, so much so that every scientific symposium for years had to include a session on reliability. During this period, almost everyone talked about reliability but almost no one really did anything about it. At first, there was not much that could be done, other than by evolutionary improvements in electronic components and by cranking back into designs the safety factors earlier removed. This meant larger equipments with reduced performance, which the customer would not accept once he had become accustomed to miniaturization. As a matter of fact, there was an increase in complexity of machines such as guided missiles and aero-space vehicles which demanded even further size reduction and increased performance. The missile required an absolute maximum of reliability for a relatively short period of time while the space vehicle needs a very high reliability for a long period. Unlike normal surface or air-borne vehicles, missiles and space vehicles, once launched, continue to the end of their mission without further opportunity for maintenance.

Today's manned aircraft and those of the future must have a high performance and speed of operation that can be met only by very complicated electronic equipment. Guided missiles once launched must thereafter guide themselves, search out their targets, and ignore decoys. Once the targets have been identified, the missiles must control their path of flight until they reach their objectives. Thus, very sophisticated high-speed computers are a necessity. The cost of getting satellites into orbit must be offset as much as possible by maximum performance for a long period of time. The ratio of payload weight to gross launch weight may be as small as one to a thousand. From an economic viewpoint these launching vehicle pounds are very expensive indeed when one considers both the cost of the vehicle as well as the rest of the launching system.

Thus, a 10-to-1 reduction of payload weight may well reduce the cost of the whole system to the point that there is an over-all reduction in cost to the taxpayer. This cost reduction incentive can make microminiaturization very attractive indeed.

The small size that can be attained by using microminiature conventional component parts such as transistors, capacitors, and the like, or the so-called solid circuits or molecular electronics, practically precludes use of human operators during fabrication, and makes automation a necessity. Although very costly at the start, automation should improve reliability tremendously, possibly to the point where the over-all cost of a system might be less than that of systems using conventional components. For example, a satellite having a dependable life of one year could justify a considerably greater initial cost than one that would operate only a month.

In addition to weapons application, there is an increasing need to telemeter the mass of data from the human body to relay its responses and reactions under duress encountered in astronautical environments. The sensors and the data transmission apparatus must be sufficiently small that they themselves do not create an unfavorable environment. The biologists need even smaller apparatus in their experiments on animals. Here it is desirable that the subjects be unencumbered with a maze of interconnecting leads. Hence, a small transmitter with enough power to relay signals up to perhaps several hundred feet is a necessity. In the search for an understanding of the apparently sophisticated communication systems of nature's small creatures, including even insects, still smaller electronic packages are required. Here is a real test for the microminiaturization experts—perhaps a hypermicrominiaturized package to attach to a honey bee, for example, to determine its communication and navigation mechanisms.

Another application of microminiaturization is in the bionics area. The self-adaptive bionic packages, as yet to be described, but which will undoubtedly contain

A special article recommended for publication by the AIEE Solid State Devices Committee.

H. V. Noble is technical director, Electronic Technology Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

synthesized neural nets along with all the redundancy necessary to insure complete reliability will have to be extremely small to fit into weapon carriers of the future. They will need to have the ability to absorb a mass of data from all types of sensors, to analyze and evaluate that which is pertinent and meaningful, and then to issue the proper control signals in an extremely short interval of time, particularly, say, when two orbiting vehicles have a closing speed in excess of 30,000 miles per hour.

It seems that the military must absorb the expense for making any great strides in the advancement of the state of the art, with commercial and civilian use capitalizing on the progress at a later date. This increased use will bring about still further improvements and cost reductions which, in turn, will benefit the military. Thus, the microminiaturization programs now under way are just the beginning of an evolution which, in the final analysis, will bring great benefits to the whole electronic industry.

Microelectronic Systems Engineering

J. D. MEINDL
ASSOCIATE MEMBER AIEE

H. JACOBS

Several general requirements for microelectronic systems are most likely to influence the nature of the future product of the components engineer. These requirements are grouped under three main headings: power dissipation, topology, and reliability.

PRIMARILY because of the advent of semiconductor devices, the past decade has witnessed considerable advance in the miniaturization of electronic systems. Although highly refined in certain instances (e.g., the Signal Corps micromodule program), a common feature of past and present miniaturization efforts has been the interconnection by wires of various active devices and passive parts to form an operating circuit. It is increasingly apparent that future progress in microelectronics will follow through mutual integration of devices, parts, and circuit. Thus far, in most microelectronics programs, emphasis has been correctly placed on the technological problems associated with the fabrication of integrated structures. However, as various programs emerge from the preliminary technology development stage, it is evident that the time has arrived for further hardware development to be more firmly guided by system-generated performance requirements.

In the past, the circuit design engineer frequently has served to bridge the gap between components and systems engineers. In view of the forthcoming generation of functional components or integrated circuits,[1,2] the exchange of intelligence between components and systems specialists must be more direct. As one natural consequence of this exchange, the components specialist will become more aware of microelectronic systems problems. It is the purpose of this article to discuss several general systems requirements which are most likely to influence the nature of the future product of the components engineer. Before proceeding further, it might be mentioned that the following list of requirements is already subject to interpretation by two individuals whose backgrounds are primarily component oriented, but whose recent experience in microelectronics has precipitated the viewpoint of this article. It is the hope of the authors that their remarks will prompt component specialists, who currently comprise the bulk of the technical manpower concentrated in microelectronics per se, toward earlier and more frequent consultation with systems engineers.

For purposes of discussion only, it is convenient to group the subject systems requirements under three broad headings: (1) power dissipation, (2) topology, and (3) reliability. As the ensuing paragraphs indicate, a rather intimate relationship among these three areas necessarily prevails in a well-designed system.

POWER DISSIPATION

THE PROBLEM of singular importance in microelectronics is that of power dissipation. Power dissipation directly affects the volume, weight, and packing density of electronic circuits through the temperature limitations of the circuit components. Dissipation affects equipment cooling and power supply requirements. It affects reliability through induced thermal stresses and through its deterrence of redundancy.

In digital circuits, which are more amenable to microelectronic techniques than continuous-wave circuits, the goal of minimum power dissipation is tempered by speed requirements, signal power levels, component tolerances, operating temperature ranges, energy source

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characteristics, and noise levels. Considering the various classes of digital circuits, transistor circuits appear most generally useful. (Tunnel diode circuits are severely limited in application by tolerance problems and parametric diode circuits by transformer and high pump frequency requirements.) The choice of a transistor circuit type favors a saturating circuit due to the decreased circuit power dissipation and the economy of components compared to nonsaturating circuits.[3,4] This discounts various types of clamped circuits as well as current mode logic (CML). Among the saturating circuits—transistor–resistor logic (TRL), resistor–capacitor–transistor logic (RCTL), direct-coupled transistor logic (DCTL), and diode–transistor logic (DTL)—the choice depends on circuit power dissipation and its influencing factors and may vary for different systems. For example, TRL is not suitable for a system where a low speed limitation is objectionable. In such cases, RCTL may suffice but only at the cost of reduced logical gain, the inclusion of a capacitor, and added use of buffer stages to reduce transient coupling. DCTL should be avoided if noise levels are relatively high. Specifically considering the foregoing objections, DTL may be a suitable compromise.

Within a restricted range, a direct relationship exists between saturating circuit speed and circuit power dissipation.[5] As the speed of operation increases, power dissipation increases. The maximum speed is limited by the finite gain–bandwidth product of the transistor, and the minimum power dissipation is determined by the low current gain limitation of the transistor. Signal power levels are not generally basic in logic circuits; however, distributed capacitance loading greatly affects the signal level required for a given speed.

It is clear that circuit power dissipation is minimized for close tolerances[6,7] including tolerances for component manufacturing, drift, and temperature variation and radiation effects, as well as tolerances for energy sources or power supplies. A trade-off of added dissipation for added tolerance is possible. As the circuit power level required for tolerance compensation increases, it may become necessary to reduce the load of a circuit. To maintain equivalent logical performance, additional circuits may be required. Consequently, system complexity may increase as a result of component and power supply tolerances.

A functional component is subjected to both externally generated noise and internal crosstalk effects. The major effect of noise on power dissipation results from external noise. Only a careful systems analysis that considers shielding, interconnections, and circuit topology can predict the circuit power level necessary to withstand external noise. Internal crosstalk is not fundamentally a function of circuit power dissipation, since decreased signal power results in reduced crosstalk. The necessity for a detailed consideration of the topological constraints imposed by internal interference is discussed in the following section of this article.

Although it is valuable to compare individual functional components with regard to power dissipation and its influencing factors, a proper comparison demands that complete logical subsystems employing different types of circuits be analyzed. For example, low-dissipation gates with low output capability may be less desirable than a high-dissipation unit with good driving capability.

TOPOLOGY

In the past, circuit topology has been influenced primarily by electrical considerations, with thermodynamic requirements relegated to a secondary position. In microelectronics, heat dissipation often may be the major consideration affecting circuit topology due to increased packaging densities. Thermodynamic topology investigations are acutely necessary in order to determine just how densely the integrated elements of microelectronic systems can be packed. Within an integrated circuit itself, components must be positioned on the substrate in such a way that the temperature of each part remains within allowable limits. Even assuming improvements in low-power integrated circuits, reliability requirements will dictate that thermal stresses be minimized in microelectronic systems.

The electrical topology of a microelectronic system must provide for maximum shielding against external noise and minimum stray coupling between internal elements to permit high-speed operation. In large systems, signals must be transmitted over relatively long distances. Here, component size reductions and high-density interconnections can alleviate the transmission time problem by reducing distributed parasitic circuit elements and the lead length. Signal leads should be routed away from clock pulse lines to minimize coupling. Power lines should be shielded to avoid nearby circuit crosstalk. Especially at speeds above 1 mc, circuit performance is strongly affected by topology and additional constraints are placed on both circuit and system topologies. The use of local ground planes, also providing shielding, may be necessary. To a larger extent than power dissipation and reliability studies, it is apparent that topological studies must be specific to particular fabrication techniques and materials, because thermal conductivities and geometrical form factors, conduction, and connection paths, etc., may vary considerably depending on the materials and processes used in the construction progress. The optimum topology for a given system will be affected primarily by the power density and bandwidth of the system.

Although system topology is most affected by power density and bandwidth, interconnections per se have an extensive influence on topology. Especially in microelectronics, advances in connectors have not kept pace with reductions in functional component size. In certain instances, recent packaging studies show that less than 10% of the over-all volume of an equipment is occupied by component cases; the remaining space serves to interconnect the components, to support them physically, and to cool them. With connectors occupying much of the volume, it is evident that great opportunity for advancement lies in improving interconnection tech-

niques. The need for more reliable external interconnections between integrated circuits is likely to become increasingly critical as the elimination of internal connections advances through integration. Where interconnections to terminal apparatus are concerned, the compatibility of the microelectronics portion of a system with such components as power transformers, rotary devices, antennas, and control panels presents unique problems. Power level incompatibilities, as well as requirements for protective devices in certain systems, may detract significantly from the benefits gained through partial microminiaturization.

RELIABILITY

SYSTEM RELIABILITY depends on the drift and catastrophic failure characteristics of the constituent parts. Basic system reliability can be modified by employing redundancy and adaptive techniques. Circuit drift failures are caused by component variations which occur in such a manner that terminal performance of a circuit extends beyond its intended design function. In order to overcome drift failures, circuits must be designed to accommodate component tolerance margins of a certain value. The values of the margins are best obtained by careful examination of manufacturer's production data, statistical life test data, and experience data. The effect of the margins on the terminal performance of the circuit may be obtained by circuit analysis and experiment. As previously stated, component tolerances are counteracted by increased circuit power dissipation. Consequently, ordinary thermal stresses in the system become more severe, and system complexity in terms of number of components increases as drift tolerance is compensated. The latter factors influence the rate of catastrophic failures—failures wherein components can be considered inoperable—and thus establish some degree of correlation between drift and catastrophic failure in a system. One may then postulate the existence of a drift tolerance margin which provides for maximum system reliability, considering both drift and catastrophic failure. The quantitative determination of this margin is an extremely complex problem of vital interest to both components and systems specialists.

Although drift failure can be virtually eliminated by designing for tolerance margins, catastrophic failure ordinarily can be reduced only by controlled manufacturing techniques and careful design and derating procedures. Redundancy[8-10] appears to offer the most attractive solution to the problem of catastrophic failure. The optimum form to be taken by redundancy must be founded on a study of failure mechanisms in a system. Three possible forms of redundancy are "standby" redundancy, "logic level" redundancy, and "component" redundancy. Standby redundancy is the oldest and best known form. In this type of redundancy, a standby is available for operation when the operating system fails. A detection and transfer device is required for failure detection and the subsequent changeover. In applying standby redundancy, the problem is to ascertain first the best level of system complexity for the application, and then the necessary failure detection and changeover devices. Logic level redundancy is employed such that a logical decision is made to decide the correct output information presented by several similar outputs. A majority vote is taken on the outputs to determine the correct output. This type of redundancy is in use in digital computers. Component redundancy is accomplished by utilizing a group of components to perform the function of a single component. If one component within the component group fails, the terminal characteristics of the group change but the group still performs its basic function. This type of redundancy is likely to be of most concern to the microelectronic components specialist. The principal difficulty encountered is the demand that a circuit be able to withstand wide tolerance margins in the terminal performance of a redundant component group. It appears that the increasing complexity of modern electronic systems demands the use of redundancy for the sake of reliability. Furthermore, through microelectronics, the technical and economic feasibility of redundancy appears greater than ever before.

A powerful approach for obtaining reliability in sophisticated microelectronic systems is the use of adaptive[11] or self-adjusting devices, which modify themselves in order to obtain optimum response from an available signal. Some means for performing this function are the well-established techniques of automatic gain control and automatic frequency control. Biological organisms incorporate this ability with a high degree of redundancy.

CONCLUSIONS

IN ASSESSING the merits and limitations of the various types of microelectronic hardware, in addition to the technological criteria, ordinarily considered by components engineers, it is well to consider additional performance requirements which are primarily system generated. The more critical system requirements center around the factors of power dissipation, thermodynamic and electrical topology, and interconnections, as well as reliability, with special emphasis on redundancy.

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Ampere-Turn Gain of Ordinary Saturable Reactors

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THE ampere-turn gain is a fundamental quantity of ordinary saturable reactors. In the case of an ideal core material with a step-shape *B-H* characteristic (rectangular *B-H* line), the relation between load-winding ampere-turns $I_L N_L$ and control-winding ampere-turns $I_C N_C$ becomes a straight line, which for identical scales of ampere-turns subtends an angle of 45 degrees with the axes. Thus, in the idealized case, the ampere-turn gain represented by the slope of the control characteristic, $I_L N_L = f(I_C N_C)$, is $K_{AT} = (I_L N_L)/(I_C N_C) = 1$.

Performance of saturable reactors is governed by the deviations of the actually measured control characteristic from the ideal 45-degree line. These deviations are due to deviations of the actual dynamic *B-H* loop of the core material from the ideal, rectangular *B-H* line. Therefore, the closer the approximation between actual and idealized *B-H* characteristic, the higher will be the performance of the saturable reactor.

This fact is particularly significant with regard to "d-c instrument transformers," which are based upon the inherent current-transformer properties of ordinary saturable reactors with rectangular-hysteresis-loop core material. Such arrangements make it possible to measure large direct currents without the use of shunt resistors; and they permit measurement of high d-c voltages in such a way that the meter circuit is isolated from the high-voltage circuit, in accordance with conventional a-c instrument-transformer techniques. In these applications, it is the object of the designer to reduce the imperfections of the saturable reactor to the minimum and to approach the ideal operating conditions (the 45-degree line) as closely as possible.

The basic requirement on a very close approximation between the actually measured control characteristic of the ordinary saturable reactor and the 45-degree line is also of paramount importance with regard to magnetic amplifiers utilizing external-feedback windings (N_F) or self-saturation. In the relevant feedback diagram, which characterizes the principle of operation of the self-saturating circuits and of equivalent external-feedback circuits with the feedback factor $h_e = N_F/N_L = 1$, the "feedback line," $I_L N_L = f(I_L N_F)$, is identical with the ideal 45-degree line of the respective ordinary saturable-reactor circuit. In this case, the deviations of the actually measured control characteristic, $I_L N_L = f(I_C N_C)$, of the ordinary saturable reactor from the theoretical 45-degree line are the basis of a simple transfer rule for the graphical determination of the entire control characteristic of an external-feedback circuit with $N_F = N_L$.

It is to be noted that the degree in which the characteristic $I_L N_L = f(I_C N_C)$ of an external-feedback circuit with $N_F = N_L$ approximates the theoretical 45-degree line is of decisive importance as regarding actual performance of "self-balancing" magnetic amplifiers operating with infinite internal gain ("critical regeneration"). As a result of the nonideal magnetic properties of core materials, the slope of this characteristic is always smaller than that of the theoretical 45-degree line. Thus, in practice it is necessary to increase the effective value of N_F correspondingly, in order to reduce the control-winding current to the minimum.

In view of these considerations, an experimental study on the ampere-turn gain of ordinary saturable reactors has been made. Actual deviations of the ordinary-saturable-reactor control characteristic from the ideal 45-degree line have been measured directly by means of a differential-type test circuit, using bifilar saturable-reactor windings, which secure correct turns ratio and eliminate magnetic leakage. Three magnetic-amplifier core materials (Silectron, Orthonol, and Supermalloy) have been investigated in this way, with various values of the effective turns ratio between d-c control windings and a-c load windings.

The results of these measurements make it evident that quite remarkable performance of d-c instrument transformers may be obtained by slightly increasing the effective ratio of primary to secondary turns and by applying a properly rated a-c bias circuit, which shifts the control characteristic in such an amount that the error-current values are minimized in the entire working range of the saturable reactor.

Discussion of the results of these measurements is also concerned with performance of the respective saturable reactor utilizing external feedback or self-saturation. In this case, the actually measured deviations of the ordinary-saturable-reactor control characteristic from the ideal 45-degree line (the "feedback line") become the very foundation on which such magnetic-amplifier circuits operate. These considerations include the typical S-shaped control characteristic causing bistable operation ("snap action"). By applying the novel test method it is possible to measure, with a high degree of accuracy, the entire S-shaped path, along which the operating point of a bistable magnetic amplifier does actually move, when snap action occurs.

It is to be noted that, in these investigations, the fundamental requirement of perfect full-wave rectification of the alternating load current (flowing through the load windings N_L) is met by employing silicon-junction diodes having a low forward resistance and an extremely high reverse resistance.

Digest of paper 61-35, "An Experimental Study of the Ampere-Turn Gain of Ordinary Saturable Reactors," recommended by the AIEE Magnetic Amplifiers Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Winter General Meeting, New York, N. Y., Jan. 29-Feb. 3, 1961. Published in AIEE *Communication and Electronics*, May 1961, pp. 173-78.

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Some Recent Developments in "Integrated Electronics"

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Integrated electronics is the new frontier in the development of the electronics industry. It characterizes microsystems in which the number of parts are considerably less than the number of equivalent components. Some of the steps in the development of microsystems leading to the process of integrated electronics are briefly described and illustrated by several working devices.

THE HISTORY of radio and electronics has followed a pattern of discovery of key phenomena leading to devices and systems which produced a revolution in communication, entertainment, industrial control and military logistics. The invention of the vacuum triode, followed by intensive activity in the theory of circuits, communications, and electromagnetics, and the development of multipurpose tubes was the revolution which ushered in the age of radio. The second revolution occurred in the decade including the war years involving the rise of new technologies such as television, military electronics, and the development of the transistor as one of many new solid-state active elements.

We are now in the midst of a third revolution, one which is the result of the synthesis of physical research, metallurgical engineering, and system design, leading to the development of microsystems. The frontier areas of microsystems, in which the number of parts are considerably less than the number of equivalent components, may be designated "integrated electronics." This combines solid-state devices (semiconductor, magnetic, cryogenic, and electroluminescent) with sophisticated systems concepts to provide a combination of functions which are just the right size for most efficient accomplishment of system requirements. These may include system optimization in the categories of reliability, performance, total cost, power-density limitations, size and weight.

Integrated electronics arose several years ago as one of several approaches to the problem of miniaturization when the quest for reduction in the size of equipments by designing increasingly smaller conventional devices and components approached a point of diminishing returns. This occurred at the stage where the associated circuitry, the supporting structures, and the space wasted due to the component form factor became, in some cases, more voluminous than the components themselves. It is estimated that such a comparison on the basis of utilized volume is less than 1/1,000 of the equipment space which, in an advanced computer, is essential to the performance of the task of computation. In Fig. 1 is shown a chart[1] of the trend of component and circuit miniaturization leading ultimately to packing densities approaching that of the human brain.

The initial phase of this new field is aimed at the reduction and possible elimination of many metallic circuit connections, thereby reducing the volume consumed by the wiring or printed circuitry, the supporting structure and the wasted space due to the component form factor. The "Shift Register Transistor,"[2] based on the thyristor principle, and the "Direct-Coupled Unipolar Transistor Logic" (DCUTL),[3] which are described herein, are two examples. In both cases several different device mechanisms are integrated into one single piece of semiconductor, whereby certain portions of the unit serve as circuit connections. Although this approach still incorporates clearly distinguishable component functions of the conventional type, the reduction of equipment size is in the order of a factor of 1,000 compared to the most advanced miniaturization schemes in current use. This is approaching the limit attainable with the known device functions of today.

The ultimate and more sophisticated endeavor of integrated electronics disassociates itself from the conventional component functions altogether, by introducing entirely different principles and concepts for the performance of complete electronic circuit tasks. New or already known physical phenomena, discovered by fundamental research, are adapted to function, not as single components, but rather as integrated circuit aggregates.

It is the purpose of this article to describe briefly some of the steps in the development of microsystems leading to the process of integrated electronics and finally to describe several working devices which have been developed at RCA under the integrated electronics program.

THE MEGACODER

ONE OF THE EARLY DEVICES which effected almost two orders of magnitude reduction in volume of an equivalent selective communication decoder was the "Megacoder."[4] This is an experimental microminiature digital decoder which can be preset to respond to any one of

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one million possible code combinations provided by a bipolar binary code. The selective calling capacity can be extended by the simple addition of identical micro-miniature modules. The Megacoder which occupied less than 1 cubic inch was incorporated in a pocket-size personal paging receiver so as to provide a personal paging system capable of selectively calling one million subscribers at rates greater than 5,000 calls per minute. Incorporated in the Megacoder is a single magnetic core-transistor shift register element, selective combinations of which perform the above coding function with less than 70 milliwatts of power.

In Fig. 2 is shown the basic digital coding waveform indicating the subscriber capacity as a function of the number of pulses which correspond to the number of shift register modules. Fig. 3(a) represents the complete Selective Call Communication System including the FSK (frequency shift keying) 150-mc transmitter and the miniature receiver containing the decoder; the block diagram of the decoder is shown in Fig. 3(b). The schematic circuit diagram of the Megacoder is shown in Fig. 4, the system concept of which involves the use of transistor magnetic core circuitry which is amenable to microminiaturization and extremely low power consumption. This is an asynchronous system in which the received pulse pattern is stored in a series of magnetic cores which have themselves a wired-in 2-polarity code. At the arrival of the wide readout pulse, both the received code pattern and the wired-in code are compared and if exact coincidence is present, an output pulse is generated which triggers an alarm or can alternately actuate any other type of control transducer. Fig. 5 shows the basic modular element of the Megacoder occupying a volume of 0.0175 cubic inch. The square loop hysteresis characteristic of the 0.080-inch ferrite core is an important feature of the shift and storage module. Fig. 6 is a photograph of the experimental Megacoder.

MICROMINIATURE PPM

An extension of these techniques was made in the area of communication and telemetry links involving Pulse Position Modulation (PPM).[5] An experimental time-division multiplex system was built incorporating a microminiature modular transistor-ferrite-core ring counter for both the transmitter modulator and receiver sampler. The pulse position modulation of the

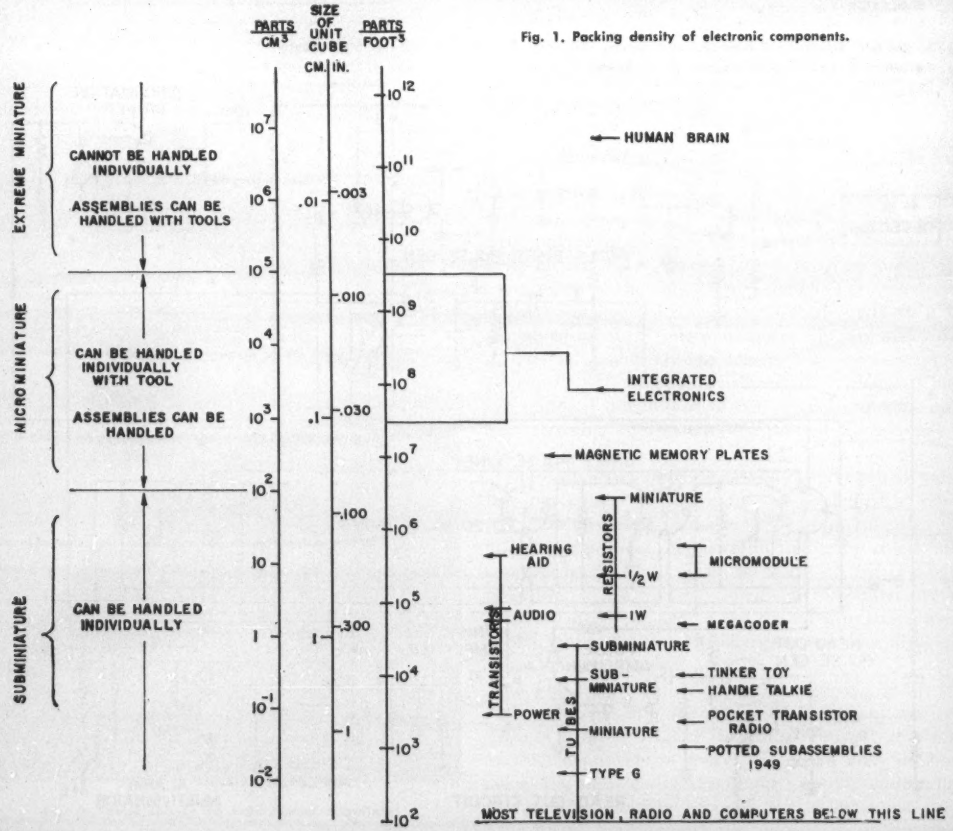


Fig. 1. Packing density of electronic components.

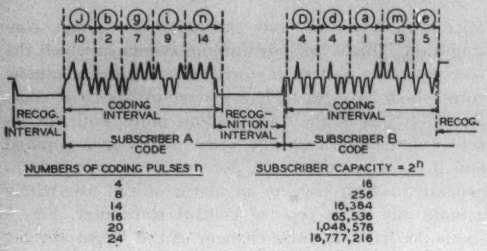
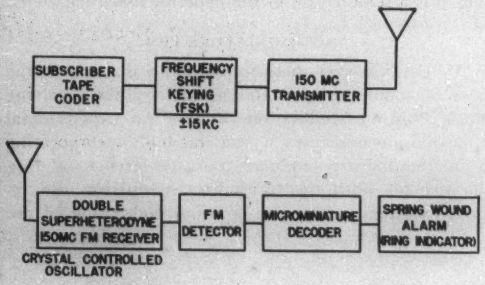


Fig. 2. Basic digital coding system.

transmitter modulator results from the variable time triggering of a modular transistor-ferrite core pulse generator by variation of either the transistor base voltage or the ferrite core coercive threshold. The sampling rate used in the experimental system was 15 kc with an upper limit set only by the high-frequency limits of both the transistor and ferrite core material used. Channel crosstalk of better than —40 db was obtained and is further improved by reduction of repetition rate. The power consumption was less than 200 milliwatts at the 15-kc rate. The linearity was adequate for voice com-



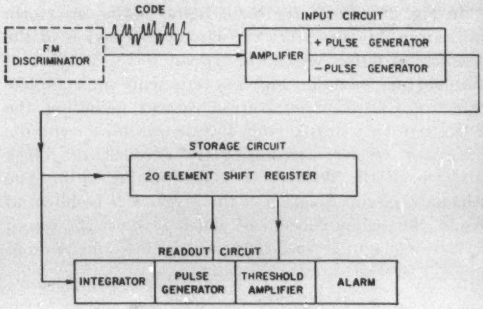
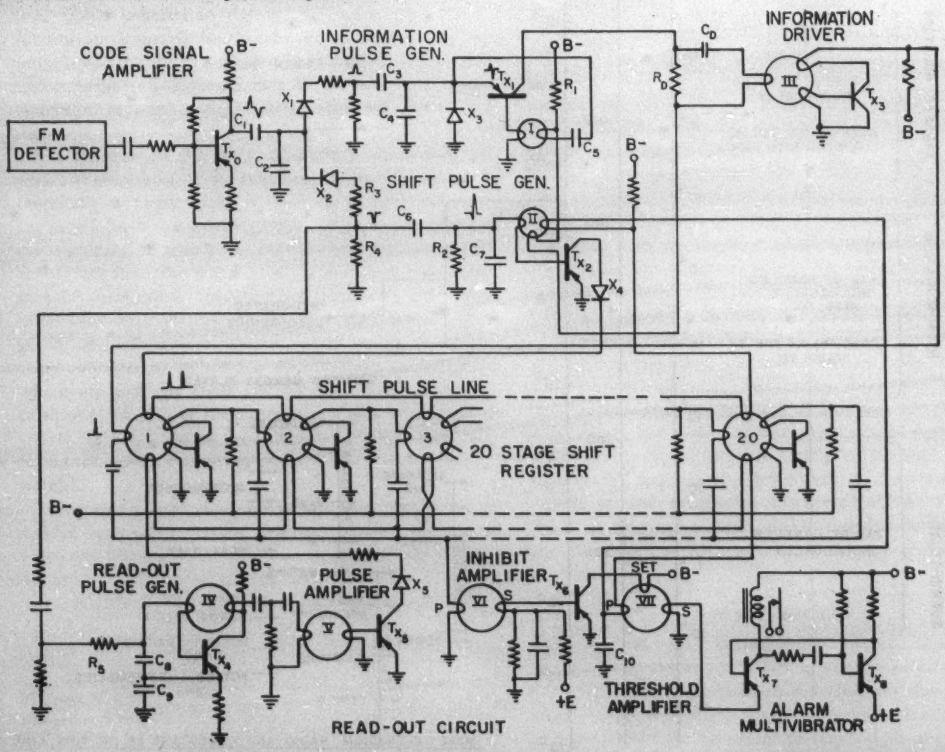


Fig. 3. [(a) *left*] Selective call communication system; [(b) *right*] paging system decoder block diagram.

Fig. 4. (below) Schematic circuit diagram of Megacoder.



munication but could be further improved by proper shaping of the modulation waveform to compensate for high order curvature of the hysteresis loop characteristic. Fig. 7 shows both the modulator (a) and the demodulator (b) block diagrams, and Fig. 8 shows the schematic circuit diagram of the modulator. The microminiature transistor-ferrite-core shift register which was developed for the Megacoder is used herein as a ring counter as well, and modifications of this circuit resulted in the development of the multivibrator clocks, and trigger and synchronizing pulse generators as shown. A photograph of the experimental microminiature versions of a multivibrator clock and a 3-stage ring counter is shown in Fig. 9.

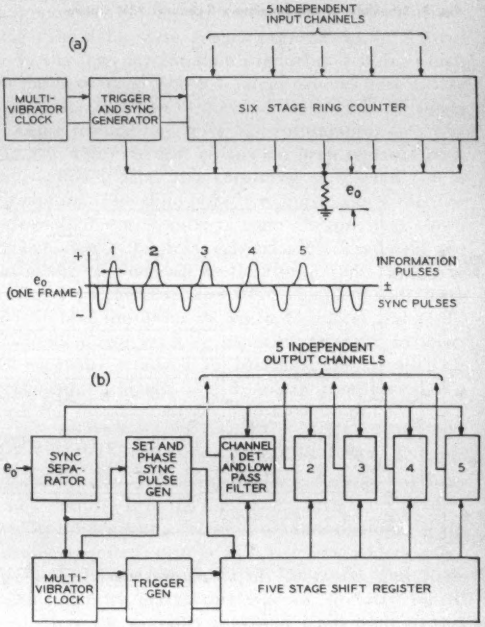
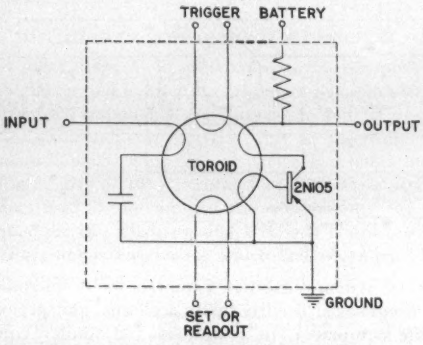


Fig. 7. (a) Block diagram of modulator and (b) block diagram of demodulator of an experimental time-division multiplex system.



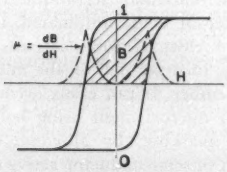


Fig. 5. Basic modular element of the Megacoder.

Fig. 6. Photograph of the experimental Megacoder.

MICROMODULES

Both these systems represent very early stages in the evolution of microsystems toward the goal of integrated electronics since they utilized miniaturized conventional components. The Micromodule[6,7] program under the sponsorship of the Signal Corps sought to develop specialized and iterated components which could then be assembled to form microminiature circuits and, ultimately, subsystems. It was basically a new concept of electronic parts packaging utilizing microelements having standard dimensions of 0.31 by 0.31 by 0.01 inch and attaining component densities of approximately one-half million per cubic foot.

In constructing a micromodule, the required member and types of microelements are assembled by stacking them according to the desired circuit function, the assembly tested and then encapsulated to provide a solid compact body of 0.35 square inch and varying in length according to its content. These micromodules are in turn assembled in aggregates representing equipment subassemblies in various arrangements depending on subsystem application.

In Fig. 10 are shown capacitive, resistive, inductive, and transistor microelements. One type of resistive module consists of four individual resistors made by vacuum deposition of nickel chromium alloy on both sides of a high-density aluminum substrate with values of resistance ranging from 10 to 100,000 ohms each,

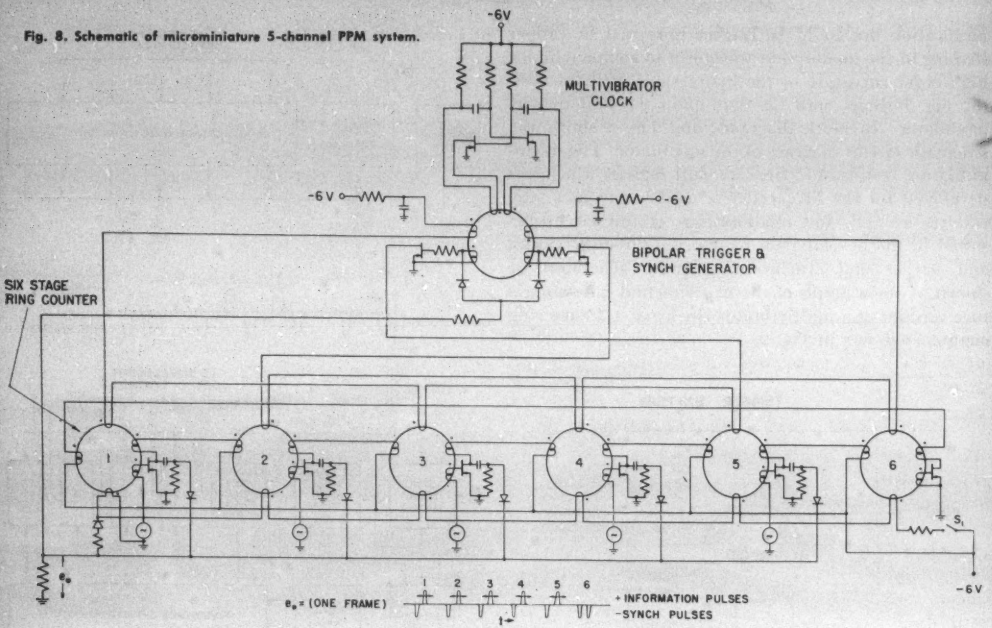


Fig. 8. Schematic of microminiature 5-channel PPM system.

having a 1/8-watt power rating and a temperature coefficient of less than 200 parts per million. Multilayered capacitive modules consisting of an integrally fired sandwich of dielectric and conductive electrodes have been made attaining capacities up to 0.3 μf for 10 layers at 50 volts and a dissipation factor of 1.5.

Other developed microelements include semiconductor diodes, shift registers, mechanical filters, quartz crystals, and semiconductor voltage variable capacitors. Fig. 11 illustrates an i-f amplifier module and Fig. 12, a microminiature modular "fountain pen" receiver and the conventional prototype which it replaced. Fig. 13 shows the application of micromodule circuitry to a newly developed airborne stable platform that reduces pickup of stray signals, requires fewer slip rings, and improves system reliability. Extensive use of micromodules is envisaged in airborne, spaceborne, and personal mobile equipment, in computers and similar equipments using large numbers of iterative devices.

Since the micromodular technique has developed substrates capable of being automated, many sophisticated integrated devices, solid circuits and similar structures can be incorporated on the microelements as a supporting member. It can easily accomplish a complete circuit per microelement using both evaporative deposition and masking, by alloying, diffusion and epitaxial growth of semiconductor active elements. The shift register module to be described in the next sec-

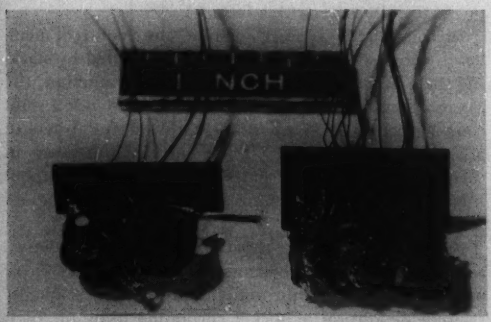


Fig. 9. Microminiature versions of a multivibrator clock (*left*) and 3-stage ring counter (*right*) before encapsulation.

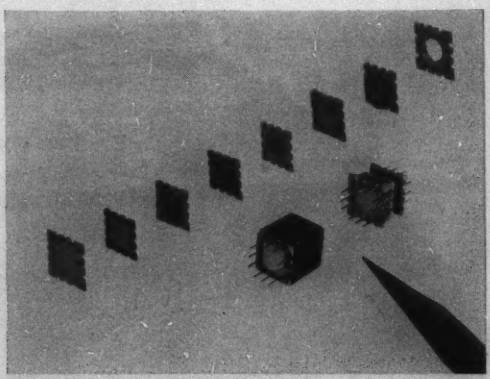


Fig. 10. View of capacitative, resistive, inductive, and transistor microelements.

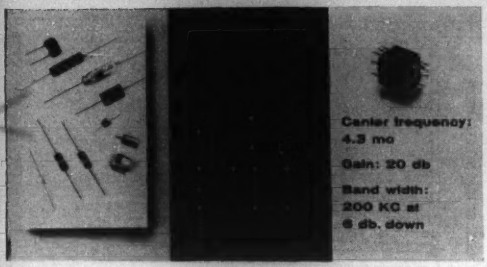


Fig. 11. An i-f amplifier module.

tion is an example of what has been attained and a hint of what the future holds for the micromodule technique.

INTEGRATED SEMICONDUCTOR DEVICES

THE NEXT STEP in the microminiaturization process was the integrated semiconductor device wherein active and passive components are incorporated in a single piece of semiconductor material with no interconnecting metallic leads. This type of device is capable of a packing density of 10^8 per cubic foot. The basic active elements used in the integrated device circuitry to be described are the Thyristor and Unipolar transistors.[8,9] The Thyristor is a transistor which behaves much like a Thyratron capable of being triggered ON and OFF using low-power drive. It has a collector voltage drop in the neighborhood of 0.5 volt during conduction with a collector current rise and fall time of less than 0.1 μsec. Because it exhibits a negative resistance characteristic within a well-defined range of current and voltage, it may be used as a bistable element to store one bit of information. Fig 14(a) shows the construction, and Fig. 14(b) typical switching characteristics of the Thyristor. One stage of a Thyristor shift register depicting the evolution from a conventional to an integrated circuit is shown in Fig. 15(a). This is a typical monostable flip-flop circuit in which the low-current state is the stable state. A shift pulse drives the Thyristor to the high-current state producing a pulse which sets the next stage. The *R-C* circuit should have a time constant long enough to store this state while the stages are being readied to receive new information.

In Fig. 15(b) the *R-C* circuit has been replaced by a semiconductor delay line consisting of a small bar of germanium. The shift pulse is applied along this bar and sends minority carriers from the ON stage down the bar. These minority carriers are collected at the end of the bar, delayed by the transit time, and serve to trigger ON the next stage. The complete shift register may take the forms shown in Fig. 15(c) and 15(d), which show two versions: elements arranged in series and elements arranged in parallel. The parallel arrangement, although slightly more complicated, reduces the shrinkage problem in fabrication.

INTEGRATED LOGICAL CIRCUITRY

AS JUST MENTIONED, the major advantage of integrated circuitry is in the digital computing art, particularly in the logic area where thousands of iterative circuits are required, such as shift registers, adders, gates, etc., and the characteristics of low-power and high-packing density makes this type of circuitry indeed ideal. Here the unipolar transistor lends itself to very efficient iterative integrated arrays. Fig. 16(a) shows a cross section of one version of a unipolar transistor with common nomenclature indicated. The resistance of the channel from the "source" to the "drain" may be varied by varying the "gate" voltage. When the gate is made negative with respect to the channel (source and/or drain), the junction depletion layer grows and encroaches upon the channel, making it narrower. There-

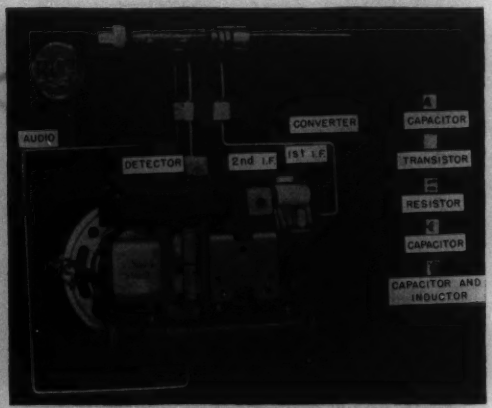
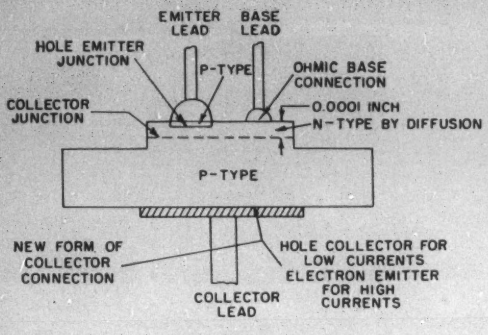


Fig. 12. Microminiature modular "fountain pen" receiver (top) and conventional prototype receiver it replaces.

Fig. 13. Application of micromodule circuitry to a high performance airborne stable platform.



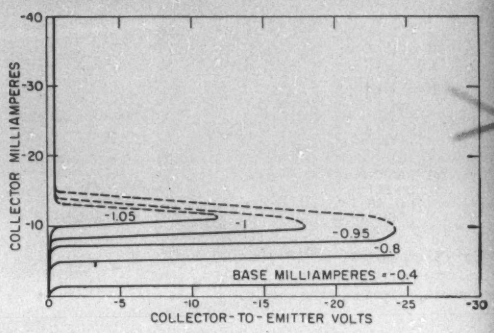


Fig. 14. The construction [(a) *left*] and typical switching characteristics [(b) *right*] of the Thyristor.

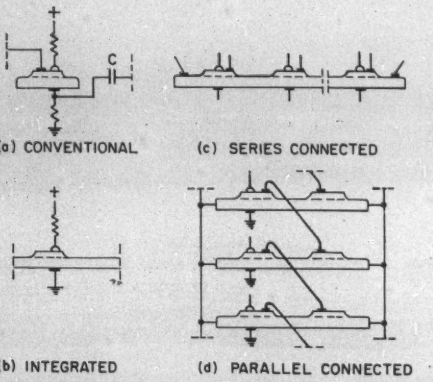
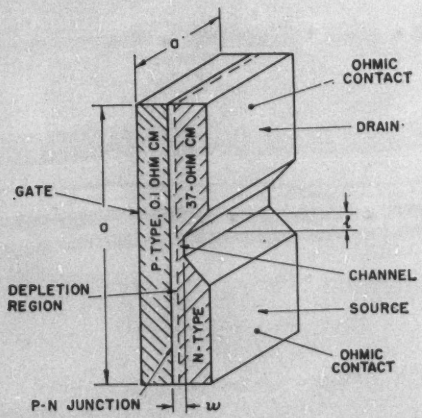


Fig. 15. (a) One stage of a Thyristor shift register depicting the evolution from a conventional to an integrated circuit; (b) R-C circuit has been replaced by a semiconductor delay line consisting of a small bar of germanium; (c) elements arranged in series; (d) elements arranged in parallel.



$a = 0.020''$
$\ell = 0.001''$
$w = 0.0005''$

fore the resistance of the channel increases, up to 100 megohms. When the gate voltage is made less negative, the channel resistance decreases. The change in resistance for the dimensions given may be obtained from Fig. 16(b) which gives some typical characteristics of a unipolar transistor. The gate is characterized by a saturation current of much less than 1 microampere with the dimensions shown in Fig. 16(a).

The unipolar transistor is in effect a voltage-controlled relay and may be used in this manner in building logic circuitry. The requirements of the unipolar transistor element from different points of view such as speed of operation, miniaturization, ease of fabrication, etc., are largely contradictory. While speed of operation favors germanium of relatively low resistivity, miniaturization favors silicon with relatively high re-

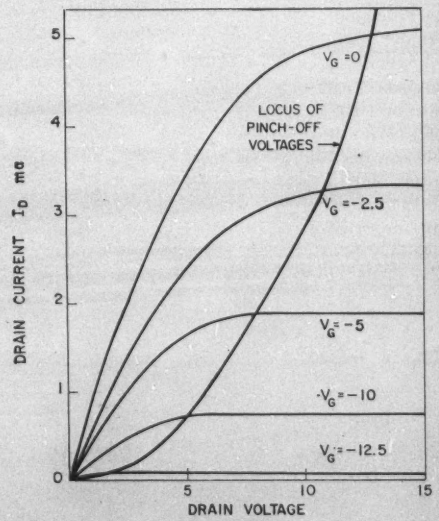
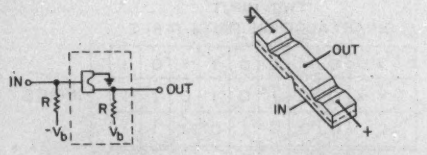


Fig. 16. [(a) *left*] Cross section of one version of a unipolar transistor with common nomenclature indicated; [(b) above] typical characteristics of unipolar transistor.



(a) BASIC BUILDING BLOCK DIRECT-COUPLED UNIPOLAR TRANSISTOR LOGIC DEVICE

(b) INTEGRATED BASIC BUILDING BLOCK COMBINING TWO UNIPOLAR TRANSISTORS

Fig. 17. (a) Basic DCUTL building block; (b) a second unipolar transistor may be substituted for the load resistance if channel width is made slightly smaller to obtain the correct resistance value.

sistivity. Since the main goal of the work reported here is extreme miniaturization, silicon was chosen for two reasons. First, the power developed per unit for given voltage and channel dimensions is proportional to the product of dielectric constant times the carrier mobility and is four to five times smaller for silicon than for germanium. Second, for given dimensions, silicon tolerates about three times higher temperature above the ambient than germanium and therefore three times higher heat flow. A further advantage is the fact that thermal conductivity of silicon is more than two times that of germanium. Silicon also allows higher resistivity at room temperature and therefore may allow a future reduction in power per stage.

Using a silicon bar having a resistivity of 37 ohms per centimeter and of the dimensions given in Fig. 16 the ON resistance is approximately 2,000 ohms. The OFF resistance can be made very high by choosing a bias beyond pinch-off. If a pinch-off voltage of —15 volts OFF, a load resistance of 4,000 ohms, and a battery voltage of 15 volts is assumed, the gate bias values become —5 volts ON.

A second integrated device[3] utilizing the unipolar transistor is called the direct-coupled unipolar transistor logic, or DCUTL.

Fig. 17(a) shows a basic DCUTL building block. The unit consists of a unipolar transistor with associated output and input load resistors. Since these building blocks are used in arrays consisting of large numbers of units in series and parallel, the output resistor of one stage may be the input resistor of the next stage. The value of the output resistor of the basic building block is not far different from that of the channel resistance of the unipolar transistor.

A second unipolar transistor may be substituted for the load resistance if the channel width is made slightly smaller to obtain the correct resistance value. The resistance of the unipolar transistor element is highly nonlinear, which is desirable in that it insures more positive switching action. The building block then becomes the device shown in Fig. 17(b).

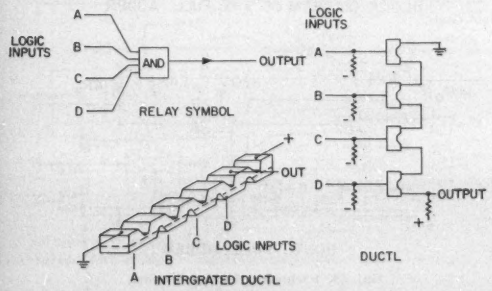
Fig. 18(a) represents a multiple AND circuit consisting of four active and one passive unipolar elements. When no signal is applied to the input gate contacts, all gates attain a large negative voltage shutting OFF all elements. When one or more gates are driven to a less negative voltage, the corresponding channel resistances shift from high to low value, turning ON the elements. However, the output voltage will remain highly positive until all gates are biased to a small negative voltage. In this case the output voltage becomes a small positive voltage corresponding to ON.

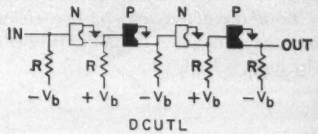
One important requirement of the building block is that a pulse passing from one end to the other does not deteriorate in shape and amplitude. Analyses of a series chain of stages such as those shown in Fig. 18(b) indicated that voltages corresponding to the ON and OFF states are stable, and propagate unchanged even through a long chain.

In the series chain shown in Fig. 18(b), alternate elements have complementary symmetry; i.e. *n*-type base elements alternate with *p*-type base elements and the voltage polarity alternates. This keeps the junctions reverse-biased at all times and requires no cascading of voltage sources. In Fig. 19 a unipolar AND gate integrated device is shown passing through the eye of a needle to illustrate its miniature size.

AN INTEGRATED BINARY HALF ADDER

Another important logic circuit is the "half adder." This circuit adds two digits in the form of ON or OFF,





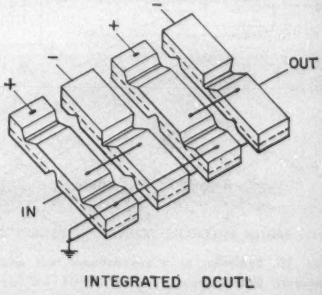


Fig. 18. [(a) *left*] Multiple "and" circuit consisting of four active and one passive unipolar elements; [(b) *right*] series chain of stages.

Fig. 19. Unipolar "and" gate integrated device passing through eye of needle.

1 or 0 pulses supplied to two inputs and delivers their sum and carry as two output pulses. Such function is conventionally performed by a score of transistors, resistors, and capacitors. Fig. 20 shows the evolution of a conventional half adder to a completely integrated DCUTL device, consisting of three small pieces of silicon so treated as to result in several active and passive unipolar elements mounted on a thin insulator wafer incorporating printed circuit connections between the elements and power supply.

AN INTEGRATED BINARY FULL ADDER

A FURTHER DEVELOPMENT of this technique is the binary "full adder"[10] which is a computer circuit that adds three binary numbers, X, Y, and a carry C, from a previous stage, giving two outputs, one for the sum and one for the carry to the next stage. A photograph of this device mounted on a micromodule wafer is shown in Fig. 21 (see cover photo). Each one of these binary numbers may be 0 to 1 corresponding to eight possible combinations as shown by the eight columns of the truth-table in Fig. 22. The design was first developed in terms of conventional circuitry, and then extended to an integrated module.

Both the active and passive elements used throughout the adder are unipolar field-effect transistors and the logic is DCUTL.

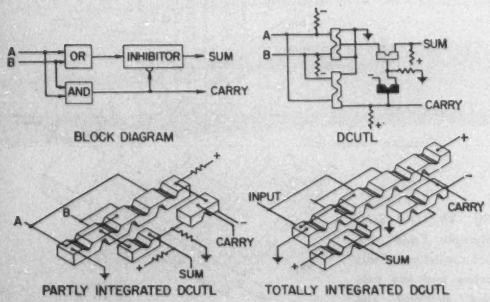


Fig. 20. Evolution of a conventional half adder to a completely integrated DCUTL device.

TWO INPUT
BINARY ADDITION TRUTH TABLE

X	0	1	0	0	1	1	0	1	INPUTS
Y	0	0	1	0	1	0	1	1	
C	0	0	0	1	0	1	1	1	
SUM	0	1	1	1	0	0	0	1	OUTPUTS
CARRY (C^{OUT})	0	0	0	0	1	1	1	1	

BOOLEAN EXPRESSIONS FOR ADDITION:

$$SUM = X\bar{Y}\bar{C} + \bar{X}Y\bar{C} + \bar{X}\bar{Y}C + XYC \quad .....1a$$

$$CARRY = XY\bar{C} + X\bar{Y}C + \bar{X}YC + XYC \quad .....1b$$

WHICH CONVERTS TO

$$SUM = (X+Y+C)C^{OUT} + XYC \quad .....2a$$

$$CARRY = XY + (X+Y)C \quad .....2b$$

Fig. 22. Boolean expressions for binary full adder.

The Boolean expressions for a binary full adder which are shown in Fig. 22 state in a shorthand form the conditions for a sum output and a carry output signal. Equations 1 (a) and 1 (b) are the most general, but all the input variables and their complements are needed. When these equations are implemented in circuit form, they contain more elements than are necessary. Equations 1(a) and 1(b) may be transformed by the use of Boolean algebra into the equivalent equations 2(a) and 2 (b). These are much more concise and appear as shown in Fig. 23 in block diagram and in integrated circuit form. This circuit contains only 16 elements, 13 active and 3 passive. The binary numbers X, Y, and C are each fed into three or four common inputs although the connecting wires are not shown. The cross-hatched units in the inverter are of com-

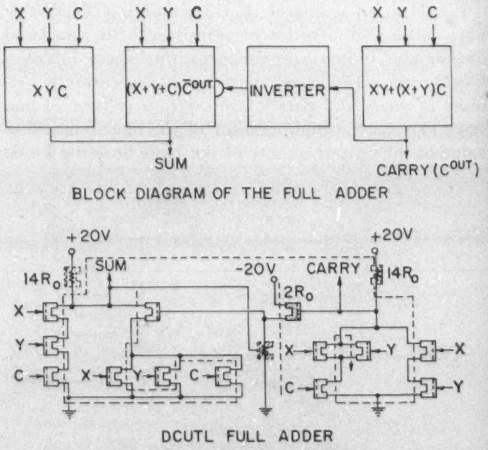


Fig. 23. Integrated circuit full adder.

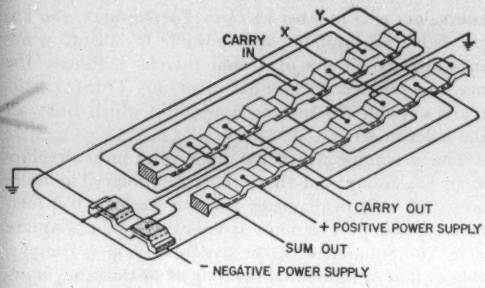


Fig. 24. N-type stick of unipolar transistor divided into two for use with micromodule wafers.

plementary symmetry having p-type channel and n-type gate whereas the other unipolar transformers have n-type channels and p-type gates. The binary number 0 is represented by a voltage level of −15 volts. Therefore, when a 0 is fed into a gate, the unipolar transistor is pinched off and represents an open circuit between source and drain. The binary number 1 on the other hand is represented by a voltage level of −5 volts which represents a moderately low resistance between source and drain.

Fig. 23 shows four elements which are different from the rest, two p-type units and two load resistors. Their equivalent resistance values are given in terms of the channel resistance R_0 of the regular units without bias. For the load resistors this means that considering their nonlinear behavior, their channels are 4.5 times as long as the channels of the regular units. The power dissipated in the circuit is extremely small.

The next step is the conversion of the above circuit into an integrated device. First the load resistors are replaced by properly dimensioned unipolar transistors. The topology of the circuit is such that a continuous path exists through the channels of all the n-type units. This continuous path is indicated by the broken line in Fig. 23; consequently, the unipolar transistor can be arranged in one row. Thereafter, the metallic connections between adjacent units are replaced by semiconductor bridges. The p-type units are handled in similar fashion and the resulting circuit is shown in Fig. 24 where the long n-type stick has been divided into two for use with micromodule wafers.

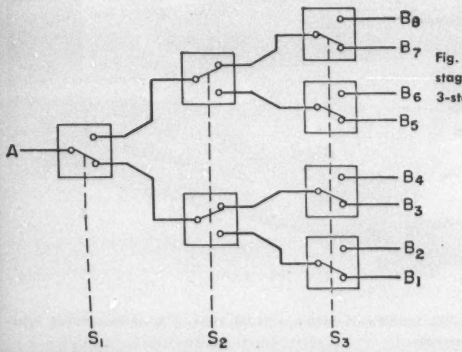
In this form there are still some connections between elements that are not adjacent, and the art of integration is the finding of a circuit layout where these connections are as short and direct as possible. These connections are made by printed circuits on ceramic micromodule wafers, and the semiconductor sticks are soldered directly to these printed circuits.

This type of integrated full adder occupies a volume of 1/400 cubic inch. The power dissipation of 200 milliwatts is readily conducted away by the ceramic wafer and by the riser wires that interconnect the adder with other wafers.

The clock rate of the breadboard model was about 40 kc and was limited by the large channel resistance of the experimental units, which had a channel length of about 0.006 inch. With improved units the speed is expected to increase by at least a factor of 10.

COMPUTER TRANSFER TREE

A MORE COMPLEX CIRCUIT known as a transfer tree is shown in Fig. 25. This unit, used to address different parts of a computer memory, is made of 24 unipolar elements connected in eight rows of three elements each. The gates of the unipolar transistors are connected to three flip-flop circuits (not shown in the figures) which give large negative bias to the gates corresponding to OFF, while the other gates are given a small negative bias corresponding to ON.



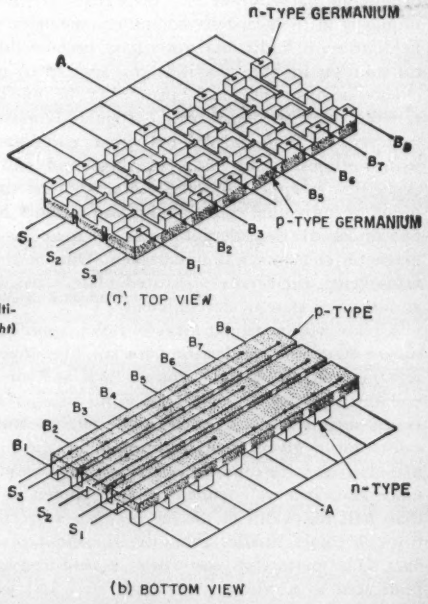


Fig. 25. *(left)* **Multistage logic tree;** *(right)* **3-stage tree.**

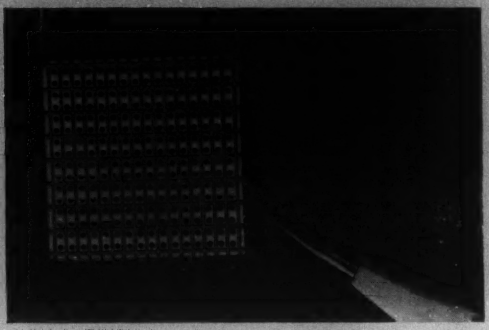


Fig. 26. View of the ferrite apertured plate.

In this manner, one and only one row of unipolar elements will be all ON, connecting the input to one of the outputs. The other rows will have at least one element in the OFF condition, thus disconnecting all other outputs. By setting the flip-flops in different states, the input may be connected to any one of the eight outputs. This principle may be extended to larger numbers if desired.

The load resistances, which again would be integrated into the device, are not shown in the figure.

Entire logic portions of a digital computer may contain nothing but integrated devices in which small silicon elements are sandwiched between ceramic insulating wafers and the sandwiches stacked.

FERRITE APERTURED PLATE MEMORIES

AN EXTREMELY IMPORTANT AREA for the application of microminiaturization and integrated electronic techniques is in high-capacity computer memories. In this field, arrays of individual cores have become the classical solution for the selective-access high-speed memory chiefly because they have proven to be much more reliable than previously used systems. Memories with hundreds of thousands of individual cores and some with millions are in use. For these and still larger capacities, it appeared some years ago that the technique of individual cores for this size memory becomes uneconomical. Considerable research to uncover other magnetic elements was undertaken. One of these developments, the ferrite apertured plate,[11] has reached an advanced state of development.

A plate with a regular array of holes is molded from square-hysteresis-loop ferrite material. The direction of remanent magnetization around each aperture stores one bit of information. There is no interference between magnetizations around adjacent apertures because, for a given current through an aperture, the magnetizing force diminishes gradually with radial distance and, at a well-defined distance chosen to be less than half the width of the leg between adjacent apertures, becomes smaller than the threshold of switch-over. The plate thus constitutes a unit conveniently fabricated as a whole in a single step and which is equivalent to a number of cores. Furthermore, the ferrite being an insulator, it is possible to "print" windings directly on the plate and thereby eliminate the need for some of the manual threading. This is particularly suitable for making a winding which links all the holes in series.

The prototype which has undergone most development has an array of $16 \times 16 = 256$ holes. The holes are 0.025 inch in diameter and are spaced 0.050 inch center-to-center. The plate is less than an inch square (Fig. 26). Squareness of the hysteresis loop is comparable to that of individual cores made of the same material. Very uniform properties from hole to hole and plate to plate have been obtained. About 300 milliampere-turns are required to switch the magnetization around an aperture at a switching time of 1.5 μsec.

The plates are most conveniently stacked with all the holes aligned to simplify interconnections (Fig. 27). The whole stack can be threaded in a single operation which does not need to be repeated separately for each plane as is customary for memory core planes. This also avoids the making of very many soldered connections. Stacks composed of 1, 4, 16, or 64 plates constitute convenient modules with which memories of various capacities can be built. Plate memories can be used in current-coincident operation or external word selection.

OPTOELECTRONIC DEVICES

A NEW APPROACH to logic networks and computer components is the application of optoelectronic[12] elements to shift registers, AND and OR circuits, adders, and logical trees. An optoelectronic element is a combination of a photoconductor (such as cadmium sulfide) whose resistance is a function of ambient illumination and an electroluminescent cell or electroluminor (zinc sulfide or selenide) which emits light by direct application of an electric voltage. Although the light amplifier[13] is an important development using an in-

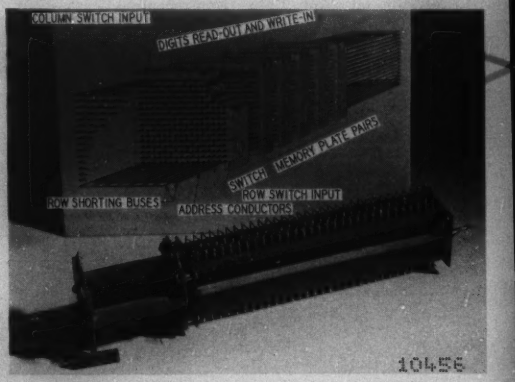


Fig. 27. Stacking of plates with all holes aligned to simplify interconnections.

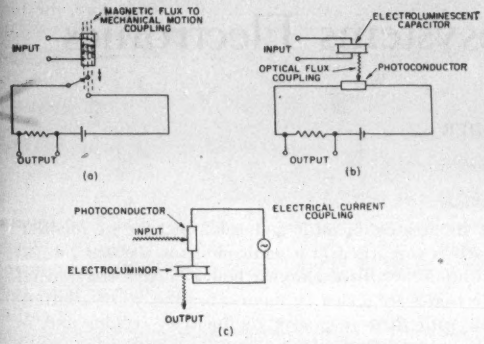


Fig. 28. Schematics of three relays; (a) electromechanical; (b) electro-optical; (c) optoelectronic.

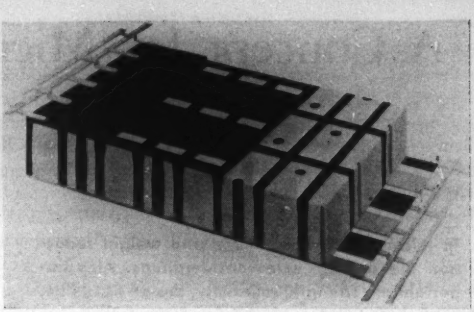


Fig. 30. Proposed structure for an array of parallel read-out shift registers.

tegrated structure of optoelectronic elements, only its application to logical networks will be discussed herein.

Fig. 28 shows the evolution of a bistable element such as a mechanical relay into an electro-optical and finally into an optoelectronic relay. The first two use electron information carriers, and mechanical or optical coupling. The third uses photons or light energy as information carriers and electrons for coupling.

Referring to Fig. 28(c), it is evident that the light emission of the electroluminor depends on the presence of photon illumination on the photoconductor. If, however, the photoconductor is exposed to the light output from the electroluminor (light feedback), the circuit will remain activated even when the input illumination is removed. This "latching" action requires a proper time constant in the recovery of the photoconductor after the input is removed. This type of behavior is essential for storage panels and optoelectronic shift registers, a schematic circuit of which is shown in Fig. 29. In Fig. 30, a proposed structure for an array of parallel readout shift registers using the above circuit is illustrated. It is evident that individual elements can be made extremely small and densely packed. The use of masked deposition, light absorbing and reflecting coatings, and evaporated conductive films allows the assembly of large numbers of low-power consuming elements into computer, visual display, and light intensifier devices and systems. The major shortcoming is the slow response compared to semiconductor and magnetic integrated devices, but the capability of simultaneous visual display will insure a fruitful field for optoelectronic microsystems.

It is evident from the foregoing that although microsystems and integrated devices have made great strides in the recent past, they are still in their infancy. The present devices, nevertheless, can make a great contribution to existing and future systems in the way of reduced power requirements, size, and weight. By the use of integrated electronics, systems of great complexity and information handling capacity and speed can become feasible from the point of view of all the parameters mentioned.

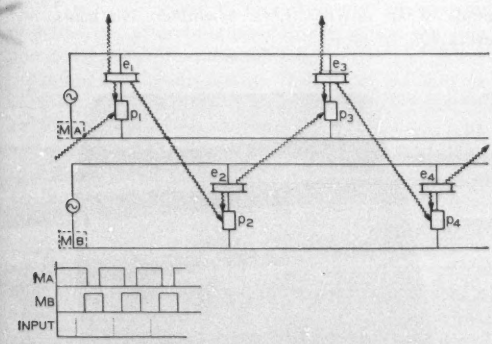


Fig. 29. Schematic of 2-stage-per-bit optoelectronic shift register employing optical priming and two electric clocks.

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A Concept for Microsystems Electronics

B. G. BENDER

In microsystem design, size and weight reduction are not the sole considerations. Also important are strength, reliability, design flexibility, heat drain, and costs. Means for automatic insertion of devices and simplicity of interconnection should be provided. All these influences are illustrated in the discussion of the assembly of Microseal diodes and transistors, and small passive components, first into circuit cards, then into a subsystem.

AN important milestone is passed when a worker in microsystems electronics learns to resist designing, at 50 or 100 times size, items which cannot be reasonably made in their intended size. Many an excursion into and thorough exploration of a blind alley can be averted by the mental exercise of considering feasibility and economics of piece parts fabrication and the sequence of events necessary to assemble an intended brainchild.

Furthermore, either designing for smallness, or just for the sake of being small or different, is wasteful and meaningless. A first consideration then must be to accomplish something worthwhile.

So it is with microcircuit packaging. Components must be designed with the idea that they are going to be used to make circuit functions, circuit functions to make subsystems, and so on.

A circuit-packaging system has been developed which attempts to provide suitable answers to many of the present-day circuit assembly problems and to avoid the ills that were already apparent in other budding microsystems, without bringing new and more horrible problems of its own.

Starting with components and targeting for minimum size and weight, the problems of ease of assembly, strength, flexibility of circuit design, repairability, reliability, power handling capacity and costs were considered. From this study, a family of microseal diodes and transistors evolved.

COMPONENTS

THESE DEVICES, photographed in Fig. 1 and shown in an exploded drawing in Fig. 2, are 0.030 inch thick. The Microseal diode is 0.062 inch in diameter, the Microseal transistor, which is egg-shaped, is 0.070 inch at its greatest breadth and 0.062 inch at its smallest. Each is comprised of a semiconductor element housed within a metallized alumina body. To this body, metal electrodes are sealed by fluxless brazing, to be continuous with their respective conductivity regions and to effect the hermetic closure of the package.

No one can deny that the devices are tiny. The fact that they are leadless further heightens the space-weight advantage.

The diode is indeed easy to assemble, ultimately automatically. It is made up of four producible pieces which can be assembled into a completed package device in a single heating operation. The sequence of events is logical and simple and all diodes in the Hughes glass package which are of interest to information handling can be thus packaged, as well as tunnel diodes and inductance devices.

The transistors with their tiny mesas are more difficult to assemble, but no more so than their electrical equivalents in the *TO-18* package. The requirement for ease of assembly is, therefore, realized.

As for strength, high alumina is noted in the ceramic industry for this property. Also, these devices have larger wall thickness-to-diameter ratios than any standard package. The package is capable of withstanding military environmental thermal shocks, and, for that matter, excursions into liquid nitrogen as well without failure. Its extremely small size and the thermal conductivity of alumina are helpful factors contributing to such survival.

Strength is further served by the fact that the devices have no wire leads. In addition to easy handling and assembly, flexure failure is forgotten. The hermetic seal does not tremble timorously or fail in the calloused hands of an unsympathetic assembler. No leads, no leverage.

Fig. 1. Hughes Microseal diode and transistor in Al_2O_3 case with metal electrodes.

A special article recommended for publication by the AIEE Solid State Devices Committee.

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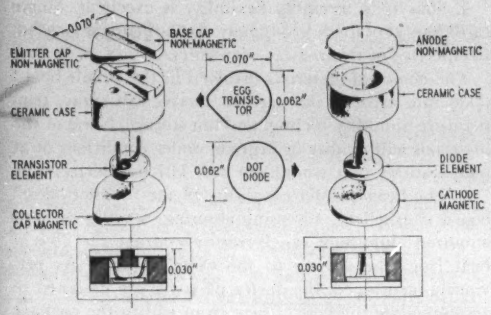

Fig. 2. Exploded views of the assembly of Hughes microseal diodes and transistors.

Flexibility of circuit design with individually packaged, pretested components of a fair range of parameters means no restrictive penalties are imposed on the circuit designer. His present freedom is not hampered.

When circuit designers reduce necessary power dissipation substantially, heat drain may not be a particular problem. However, increasing packing densities now force close attention on this problem. Leadless packages, by virtue of full-face contact with the device on the inside and large cross-sectional exposure on the outside, offer extremely low thermal impedance for flow of heat from the junction.

Reliability has become an increasingly important word and activity at Hughes and throughout the electronic industry, as the space-age breaks over us. Prospective purchasers of microcomponents have grown to expect reliability to move inversely with size. Microseal devices will have the benefit of this reliability awareness and activity and have one more factor in their favor. Identical sized junctions are packaged in a chamber whose volume is one to three orders of magnitude smaller than present-day components. This means Microseal devices have packaged with them proportionately less volume of gas and, therefore, water vapor, the arch enemy of semiconductor surfaces. However, reliability is never proved in the laboratory, but in years of actual use, so nothing more can be said at this time and be meaningful on this subject.

From a standpoint of costs, the picture is highly favorable. A device must have a semiconductor element in any event, but economical techniques have been developed for producing chips for the Microseal effort which have advanced the state of the art. Piece parts are mass producible and forecasts of pricing in large quantities can sharply reduce the cost of the package compared to standard parts. Automatic assembly, to which Microseal devices are eminently susceptible, makes the future cost picture even brighter. These devices also feature properties that permit both visual and mechanical polarity descrimination. This means automatic circuit assembly is possible when needed and hand assembly is facilitated.

CIRCUIT ASSEMBLY CONCEPT

CIRCUITS ARE NOT BUILT with semiconductors alone; therefore, concurrent with this effort, some 250 passive components manufacturers were contacted to determine their reaction to producing parts compatible with the above described active elements. Those companies making positive responses have been encouraged with orders; items received are evaluated and circuits built. The circuits which have been fabricated include a rectifier network, a blocking oscillator, an audio amplifier, and a binary flip flop (Fig. 3.).

These circuits were built, employing a technique which is called "Swiss Cheese," the origin of which is obvious from Fig. 3. Now we shall see how the devices were designed with the idea that they are to be used in a circuit.

"Swiss Cheese" involves placement of suitably arranged holes in a 0.030-inch-thick circuit board. These holes, then, are the device sites. When placed in their proper array (Fig. 4), the components are then connected mechanically to the board and electrically to each other by virtue of stenciling or spraying a conductive adhesive through a metal mask. A similar operation performed, on the opposite side of the board, completes the circuit so that the devices, acting as feedthroughs, thread the circuit between the two faces.

This circuit assembly technique is equally applicable to etched circuit boards and to blank boards. In the latter case, the metal mask is opened to include printing the circuit pattern concurrently with fixing the devices in place.

A wide variety of substrate materials lend themselves to this technique. The ceramics, including glass, hard anodized aluminum, glass-epoxy and paper epoxy, are some which have been successfully utilized. Packing

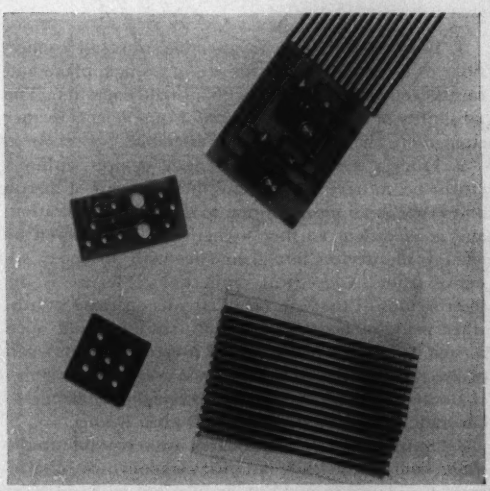

Fig. 3. Operating binary flip-flop circuit in the "Swiss Cheese" concept, using Hughes Microseal active components and Hughes contour cable. Other circuit boards are also shown.

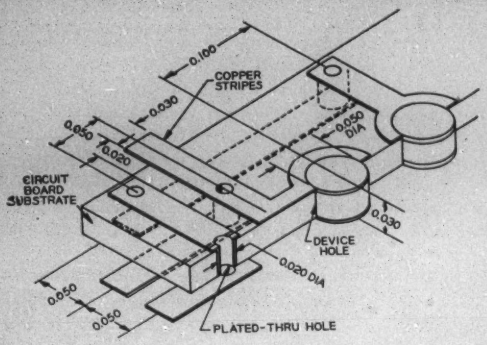

Fig. 4. Cutaway of a "Swiss Cheese" circuit assembly, showing Hughes Microseal diodes positioned in the device sites and circuit stripes.

density and power dissipation will likely determine the best choice for a particular application since they will tip the cost vs. utility balance.

The economics and ease of accomplishing circuit assemblies by this method is certainly obvious. What may be less obvious is the fact that the interconnection problem can be sharply reduced. A case in point is a delay line (fabricated by the Hughes Communications Division) normally comprised of some 300 components and 219 interconnections. When laid out for "Swiss Cheese" fabrication, this circuit not only had the space-weight advantages, but required only 20 interconnections.

Some readers may turn up their noses at the idea of conductive adhesives. However, it is likely that for the last 8 to 10 years many of these persons have been using glass diodes that have their crystals mounted to the package by use of a member of this family.

What has been accomplished by this circuit assembly system?

1. It is certainly easy to assemble, since all connections to be made on one side are in a single plane and can be stenciled or sprayed with a single operation. The possibility of automatic insertion of components further strengthens the case for ease of assembly.

2. From a standpoint of strength, devices within a circuit board have the least possible moments of inertia and so are in an ideal position to resist shock, vibration, and acceleration. Further strength can be achieved by affixing the devices into their sites with an epoxy adhesive prior to electrical connections. Flexure is the most serious ill that can befall circuits on these boards, when made of nonrigid materials, since it could open a circuit. This hazard is limited if cards are kept small or are racked. However, if extreme acceleration or mechanical shock are anticipated, it might be better to choose a ceramic board which will resist flexing.

3. "Swiss Cheese" circuit boards are repairable to the single component level. A failed component can be removed and a new one put in its place with no more equipment than a pen knife, a fine paint brush and a vial of adhesive.

4. Subsystem assembly flexibility is excellent. Single cards can contain few or many components as needed, irrespective of throw-away economics.

The choice of materials involved in the circuit board takes into account the need to survive salt spray, temperature-humidity cycling, and hot storage. None of the materials will oxidize or degrade under conditions or at temperatures that would not also kill the devices.

5. The heat transfer capability of the "Swiss Cheese" board is excellent. Choosing alumina, beryllia or hard anodized aluminum can further encourage the flow of heat from the devices to the outer package. As previously mentioned, the device packages are designed to accommodate the flow of heat from within the package to the electrodes. To point up this fact, it is worth mentioning that certain of the Microseal diodes have the astonishing ability of passing more than two amperes at +1 volt, without damage to the junction. However, we are not yet prepared to recommend this practice.

Assembly of "Swiss Cheese" circuits is an achievement, but it is not an end. For this concept, the end is a subsystem which can be used. Connecting boards to each other and, thence, to a useful system is the goal.

Again, we find "Swiss Cheese" to be flexible. It is amenable to a variety of interconnects. Pins, contour cable or wires can carry the circuit in and out. Attachment of those is possible by conductive adhesive, soldering, or ultrasonic welding.

Contour cable (Fig. 3), is of particular interest as an interconnect since it offers the possibility of close packing with the chassis closed, yet permits easy trouble-shooting while the system operates with the chassis off, since the boards can be leaved and test-probed.

OTHER APPLICATIONS

Workers engaged in thin film *R-C* networks have recognized the possibilities of a marriage of their techniques with Microseal devices within the framework of "Swiss Cheese." Solid-state circuit functions, some of which are 0.030 inch thick, can also be wed to "Swiss Cheese" within an 0.030-inch circuit board and thus find broader application. It has been further observed that Microseal devices might be useful in the micropackaging programs of others not using "Swiss Cheese" for circuit assembly. An example might be the Signal Services Agency's micromodule program.

CONCLUSION

The results of this work to date then, are a family of minimal packaged semiconductor devices of a broad range of usefulness and a micropackaging concept which is extremely flexible, simple, and economical to assemble, having circuit design flexibility and inherent reliability.

It is recognized that the power-handling capability of the system will limit its usefulness to information handling and systems using detector-type input transducers but as circuit designers find means to reduce power requirements, it may be possible to build whole systems in "Swiss Cheese."

A Method for the Design of Holding Electromagnets

J. T. LUDWIG
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IN DESIGNING cylindrical holding electromagnets, which consist of a ferromagnetic core, with stationary and movable portions, interlinking a coil of wire, it is desirable to proceed from the specified mechanical and electrical characteristics directly to the physical dimensions of the magnet without the use of trial-and-error methods.

These electromagnets are required to hold a switch or contact assembly in a given position as long as power is applied, and to release it when power is removed. The electromagnet is not required to pull in the contact assembly; this is done by other means.

The design of a holding electromagnet can be treated directly as a synthesis problem. The fundamental equations can be used as a theoretical foundation for a straightforward design method.

When materials having nonlinear characteristics are involved, the direct design methods often make use of "derived" material characteristics. These derived characteristics are mathematical combinations of the traditionally measured "fundamental" characteristics.

The first step in the synthesis of a holding electromagnet is the determination of the optimum magnetic operating point from a chart which is derived from the magnetic circuit equations and material characteristics. The index function (abscissa) is the ratio of hold-in force to drop-out force, F_1/F_2. Four application functions are given on the chart:

1. Operating induction, B_1
2. Effective reluctivity, $(1/\mu_{11}) + \alpha$
3. Fractional air gap, α
4. Effective magnetizing force, $\overline{H_1}$

The effective reluctivity is a measure of relative size; for fixed values of force and heat-power density, the volume required is proportional to the square of the effective reluctivity. The merit of various magnetic core materials for a particular set of specifications may be determined by comparing their effective reluctivities for the force ratio F_1/F_2 in question.

The operating induction B_1 is used together with the hold-in force F_1 and the central hole size, radius r_1, to determine the plunger size, radius r_2.

The effective magnetizing force $\overline{H_1}$ is used, together with the other known factors, to calculate the characteristic thickness t_o, which is the asymptotic value that the thickness t approaches for large outside radius r_4 values.

Fig. 1 is a plot of t/t_o vs. r_4/r_2, with r_1/r_2 as a parameter. The thickness t has been normalized in terms of t_o; and the hole radius r_1 and the outside radius r_4 have been normalized in terms of r_2. Both of the normalizing factors, t_o and r_2, have been found in the previous steps.

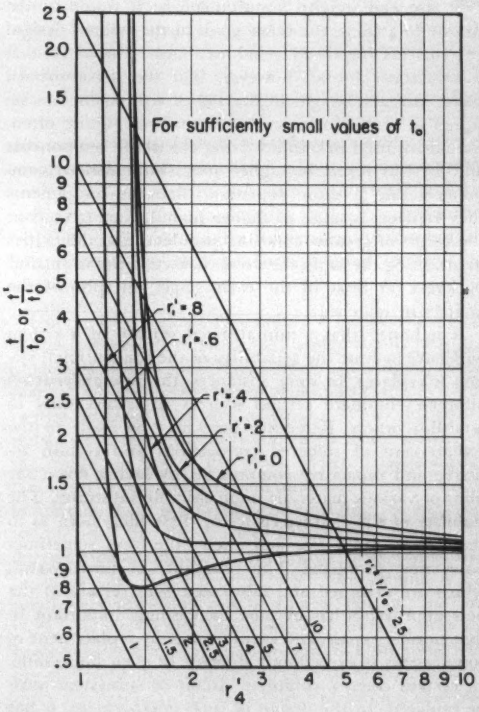

Fig. 1. Geometrical designs.

The diagonal lines are lines of constant volume which facilitate volume comparisons of designs with various t and r_4 values. The minimum volume design may readily be determined, as well as the relative volume increase with shifts away from the minimum volume design. The chart can be used to design for minimum volume, for specified r_4, or for specified t. Once these values have been established, the rest of the design is readily computed.

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Molecular Electronics and Microsystems

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The molecular electronics approach to microsystems considers the electronic function to be performed, then attempts to synthesize its characteristics within a suitable solid material. It is expected that this approach will lead to many new concepts in the realization of electronic functions.

THE PRIME OBJECTIVE in any considerations of the subject of microsystems is the reduction of size and weight. Simultaneously, it would be desirable to achieve the other goals of the systems designers, such as improved reliability and reduced cost. It is sometimes found, however, that the drive toward better size and weight utilization of equipment has resulted in actual increases in original cost. Quite often, the means used in miniaturizing electronic components and systems result in higher costs. Miniaturized components can be more expensive than the components they replace, because of higher manufacturing costs as the result of greater handling problems and difficulties in attaining the same electrical characteristics in smaller packages, at least in the early stages, in spite of the savings in materials.

It is hoped that a miniaturized version of a system will have at least the reliability of the conventional system it replaces. In some instances, the new approaches adopted eliminate certain sources of failure only to establish others. Reference here may be made to the replacement of soldered connections and certain resistive and capacitive components by laying down the films of various materials upon suitable substrates. The stability of the characteristics of these films both as to their bulk properties and their interfaces sometimes poses new problems. The reliability of microsystems which are designed and fabricated with certain of the new approaches has become increasingly important in that normal repair, and maintenance by replacement of components is exceedingly difficult or even impossible. In certain cases, a complete circuit or subsystem must be replaced. In the design of such microsystems, it has been convenient to package portions of the system to permit quick checking for faults and to permit easy removal and replacement. The division of an electronic system into subsystem packages must be carefully considered from the maintenance viewpoint and from economic considerations involved, particularly if the package must be thrown away.

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TRENDS IN MICROMINIATURIZATION

WHERE small size and weight are the most important factors, increased cost may sometimes be tolerated. A trend toward size and weight reduction of electronic systems has been evident for many years. Electronic equipment size and weight reduction has been achieved in close co-operation with the manufacturers of electronic components. Conventional electronic components such as vacuum tubes, resistors, capacitors, and transformers have been shrunk considerably, in some instances to the extent that assembly and wiring of these by conventional methods have become burdensome. The replacement of electronic vacuum tubes by solid-state devices was an important step in the direction of systems miniaturization.

In addition, the trend toward microsystems is being realized by the elimination of space normally occupied by the circuit-supporting structures and interconnecting wiring which may represent a large percentage of the system's bulk. Electronic microsystems are being achieved through normal component shrinkage, new form of components, and new interconnection methods, as well as by reduction of support structure size and weight.

For purposes of convenient maintenance, design, testing, assembly and manufacturability, systems are very often broken down into logical sections or subsystems, i.e., they are modularized. A modularized package may consist of a circuit to perform a readily recognizable function which is part of the over-all system. The functional module may consist of an assembly of smaller modules and, in some instances, the smaller module (micromodule) may bear only a single conventional component, such as a transistor, capacitor, or resistor. Modular packages of electronic circuitry are normally interconnected by soldered or welded wiring or by soldering into printed-circuit boards. In some cases, modularized packages are inserted into interconnecting printed-circuit boards where contact is made by some form of spring. Modules may consist of one or more conventional circuit components supported upon a substrate and interconnected by soldering or they may consist of evaporated thin film structures which are laid down to form resistors, capacitors, etc., together with metallic low-resistance interconnections.

MICROMINIATURIZATION THROUGH MOLECULAR ELECTRONICS

THE MOLECULAR ELECTRONICS approach to microsystems considers first the electronic function to be performed and attempts to synthesize its characteristics within a suitable solid material. Since a complete system usually is too large to handle conveniently as a

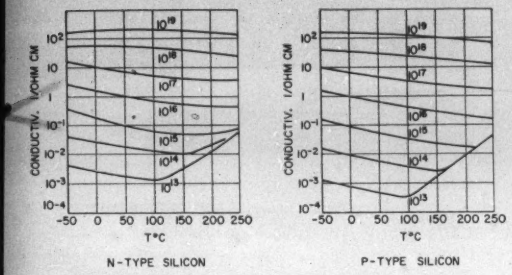


Fig. 1. Silicon conductivity vs. impurity levels and temperature.

single monolith, the whole system is divided into smaller subsystems which at the present time may be joined externally by any one of the already mentioned means for interconnecting modular packages. In molecular engineering, it has been found convenient to work with certain subsystems which encompass recognizable electronic functions, such as amplifiers, multivibrators, oscillators, pulse generators, NOR logic elements, etc. This is also desirable in new systems development, since these are the common building blocks of many complex systems. The name "functional electronic block" has been given to these self-contained subsystems.

Basic Materials in Molecular Electronics. Solid semiconductors have been very extensively investigated since the invention of the transistor. Fundamental properties of single-crystal semiconductor materials are fairly well understood and the wide variety of useful electronic phenomena possible with such materials makes them a logical starting material for functional electronic blocks. Techniques have been evolved for altering semiconductor properties to provide a wide range of electrical conductivity. In silicon, for example, resistivities of less than 1 ohm-cm to 5,000 ohm-cm are possible. Fig. 1 shows the dependency of the conductivity of silicon upon various doping levels and temperatures. The positive temperature coefficient of such materials over a large temperature range can be useful in temperature stabilization of functional blocks which may have other regions showing negative temperature coefficients. Selected portions of a semiconductor section may be modified to produce regions of either n-type or p-type conductivities with great precision. Multiregion structures in semiconductor crystal materials have provided electronic phenomena which form the basis for a large variety of electronic devices. Table I is a partial listing of such devices, giving the number of regions involved and the basic effects occurring at the junctions or boundaries of these regions.

Table I. Electronic Effects in Solid Semiconductors

Number of Junctions	Number of Regions	Junction Electrical Properties	Device Examples
1	2	Rectification, tunneling, injection, recombination, capacitance, field effect.	Rectifiers, diodes, capacitors, unipolar transistors, unijunction transistors.
2	3	Injection, recombination.	Bipolar transistors.
3	4	Injection, recombination, capacitance.	Dynistor, Trinistor, oscillator, hook transistor, multiposition switches.
4	5	Injection, recombination, capacitance.	Current multiplier, multivibrator, pulse generator.

All of the aforementioned properties of semiconductor silicon material and the accompanying electronic effects have been incorporated into the designs of functional electronic blocks. When these are discovered, new basic phenomena in solid semiconductors may be incorporated into functional block designs. It has been found that the design of functional electronic blocks in 3-dimensional semiconductor materials has yielded electrical performance and characteristics not easily duplicated with conventionally connected lumped components. Although conventional equivalent circuits are still used in many cases to describe the performance of an electronic functional block, these are only aproximations which are useful in that they provide a familiar medium for discussion of results. A more accurate description might involve the analysis of current carrier flow through the semiconductor material in three dimensions.

Unique Effects in a Semiconductor Functional Block. While it is feasible to fabricate distinguishable resistors, capacitors, diodes, and transistors in a functional block, there is a limit to the degree of miniaturization which can be achieved with this approach. When dissipative resistance is used, the heat generated in the block sets the minimum size of the block. When a large capacitance, say a few hundred microfarads, is incorporated in a block, there is great difficulty making the size compatible with the miniaturized functional block. An inductance based on the magnetic-flux principle cannot be made very small because when the volume is too small, very little flux can be linked. For junction devices, the size of the junctions, the contacts, and the leads have approached an almost irreducible limit with present technology, i.e., photographic techniques. All these facts point to the importance of seeking new phenomena and unconventional approaches if further reduction in size is to be achieved. So long as an elec-

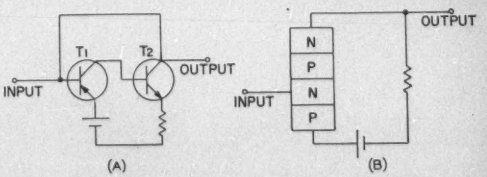


Fig. 2. (A) Bistable multivibrator; (B) 4-layer multivibrator.

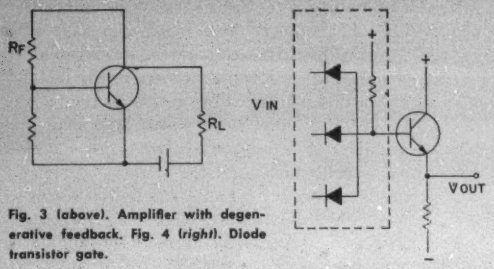


Fig. 3 (above). Amplifier with degenerative feedback. Fig. 4 (right). Diode transistor gate.

tronic function is accomplished, there is no necessity for the functional block to contain certain component analogs. As a matter of fact, there are many semiconductor phenomena which do not have a ready equivalence in conventional lumped component circuits but can be utilized to perform electronic functions.

Some such phenomena can be utilized to obtain the functions of L, R, and C in a much smaller volume than their conventional counterparts. Other phenomena can be utilized to perform circuit functions without resorting to the integration of L, R, and C values, sometimes yielding better results.

The realm of such phenomena is quite extensive and there are a great many possibilities which must yet be explored. The following are a few either unconventional or unique effects which have already been incorporated in the fabrication of functional electronic blocks:

1. *Multiple Use of Common Region.* In a semiconductor functional block, the same conductivity region may serve many purposes. The 4-layer structure is a good example of this principle. Fig. 2(A) shows a p-n-p transistor cascaded with an n-p-n transistor to form a bistable multivibrator. As shown in Fig. 2(A), the p-type collector of one transistor is connected to the p-type base of the other transistor. Similarly the n-type collector of T_2 is connected to the n-type base of T_1. The 4-layer structure in Fig. 2 (B) performs in the same manner. However, the inner p-layer serves the dual function as a collector of T_1 and base of T_2, and the n-layer as the collector of T_2 and base of T_1. In this way, savings are obtained in material and in interconnections, and miniaturization is inherent. In the large variety of functional blocks built so far, this principle has been utilized over and over again.

2. *Temperature Compensation by Intimate Thermal Coupling.* Most semiconductor devices are temperature sensitive. In most applications, it is required to furnish some temperature stabilization or compensation means. For instance, in most transistor amplifiers, current degeneration is commonly used in low-level stages, and bias compensation is sometimes used in high-level stages. One commonly used degeneration means is shunt feedback. This can be applied over one or more stages as shown in Fig. 3. The feedback factor is essentially equal to the ratio of the load resistance R_L to the feedback resistance R_F. When bulk semiconductor resistances are used in a functional block, the resistance values may vary as temperature is varied. By incorporating these resistances in a monolith, the temperature is nearly uniform. Because the percentage variation of resistance with temperature is the same, the ratio R_L/R_F does not vary in spite of individual variations.

To compensate for the variation of base–emitter voltage with temperature, a temperature dependent bias is sometimes used (especially in high-power stages). For effective compensation, a close thermal coupling should be established between the transistor to be compensated and the compensating element, so as to keep both of them at the same temperature. In a monolithic structure, the close thermal coupling between different regions is inherent.

Both temperature compensation and temperature stabilization are used to good advantage in some of the functional blocks to be described later, such as amplifiers, analog bistable multivibrators, and analog multipliers.

3. *Matching of Functional Characteristics.* In component circuits, it is common practice to specify the tolerances for the individual components in order to make sure that the combined circuit will function properly. The tolerance requirements must sometimes be very stringent, because one does not always know the other components with which one particular component is to be used and hence must design for the worst case. In a functional block where many different areas can be processed at the same time, the chances of obtaining uniform characteristics are greater than with the assembling of randomly selected components. This particularly applies for switching functional blocks where many repetitive functions are performed. For example, consider the case of a diode AND gate shown inside the dotted line in Fig. 4. There are many diodes connected in parallel. When this gate is to be fabricated in a functional block, the uniformity of the junctions is good because all the junctions are processed at the same time.

Where only the electronic function is of interest, not all the individual areas need always be closely controlled. Again, take the diode transistor logical gate as shown in Fig. 4. It is important to have the output voltage follow very closely the lower of the input voltages. If component circuits are used, it is important

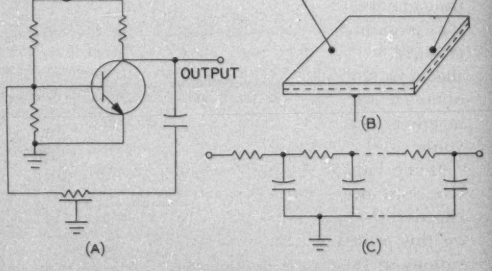


Fig. 5. (A) Phase-shift oscillator; (B) Semiconductor network structure; (C) Equivalent circuit of semiconductor network.

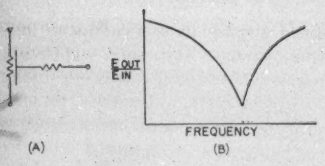


Fig. 6. (A) Null filter; (B) Transmitted characteristic of null filter.

to specify all the diodes, the transistor, and the resistors to a very close tolerance. In a functional block, it is possible to tailor only, say, the base biasing resistance R_B to match the other regions. Other examples of this feature are found in the tunnel flip-flop, the logical switches, etc.

4. *Distributed Parameters.* The design of circuits in 3-dimensional solid semiconductor materials permits the synthesis of distributed parameter networks which can be simulated only with complex arrays of conventional lumped components. Fig. 5 (A) illustrates the use of a distributed semiconductor network in a phase-shift oscillator. The network may be very simply fabricated as shown in Fig. 5 (B). Its equivalent in lumped components can be represented by Fig. 5 (C). The semiconductor version consists of a resistance distributed over an inversely biased p-n junction, the capacitance of which may be varied according to the bias applied; a feature which may be utilized to tune the oscillator over a wide frequency range. The characteristics of the distributed *R-C* network may be further altered by tapering its resistance or capacitance in a large variety of geometries. If a lumped resistance is incorporated, as shown in Fig. 6(A), a null may be obtained in its transmitted characteristics; see Fig. 6 (B). Such a filter may be used in the feedback loop of an amplifier to produce a selective frequency bandpass amplifier.[1]

5. *Minority Carrier Delay Effect and Conductivity Modulation.* In high-frequency transistors, the transit time of minority carriers should be minimized. On the other hand, the diffusion of the minority carriers is in some manner like a delay line. This delay action can be utilized. The effect can be combined with the conductivity modulation effect to produce inductance. When a forward voltage is applied across a junction, the conductance is lower at the first instant and becomes higher as the carriers sweep through the region due to the minority carrier delay effect. This time variation of resistance simulates the inductive effect.[2] The transit time may be changed by changing the electric field, and the amount of conductivity modulation may be changed by changing the injection, thereby changing the inductance. Large values of inductance have been obtained without the necessity for the conventional magnetic reaction, which invariably results in large volume.

If the inductive effect is combined with some negative resistance in certain junction structures, very high effective Q can be obtained. Tunable structures based on this principle have been built and may find applications in functional blocks.

6. *Transverse Electric Field.* In either the unipolar structure or the bipolar structure, a transverse electric field may be applied to produce some continuous nonmechanical effects not easily obtainable with finite or lumped components.

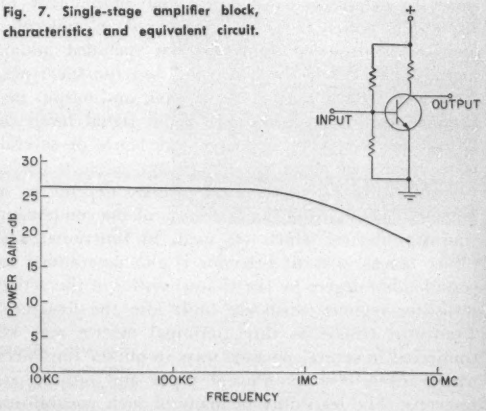
In the unipolar structure the use of transverse electric field has resulted in a current-limiting action.[3] The electric field transverse to the current flow from the source to the drain produces a depletion layer which "pinches off" the current at a certain level. This effect can be very simply and advantageously designed into functional electronic blocks. In bipolar structures, the transverse electric field has been demonstrated to deflect the injected minority carriers. The commutator-type switch[4] to be described later and certain multiple-collector functional blocks[5] are based on this effect. The action is similar to that of a rotary switch. The action can also be continuous, as in a potentiometer.

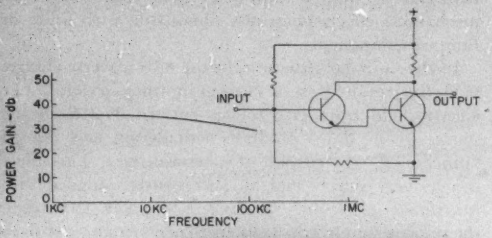
FUNCTIONAL BLOCK DESIGN AND DEVELOPMENT

A LARGE NUMBER of electronic functions have been incorporated into single crystal blocks of silicon or germanium. These include amplifiers of many descriptions; oscillators; detectors; demodulators; modulators; mixers; flip-flops; astable, monostable, and bistable multivibrators; logic gates such as the NOR, STROKE, AND, OR; complex electronic switches; and others. The electrical characteristics and the structures evolved on several of these will be presented in detail in subsequent sections of this article.

The procedure in the design of a functional electronic block begins with a study and analysis of the existing conventionalized circuit (where such exists) to gain a thorough understanding of the function performed. In many cases, the conventional circuit may contain components which are not realizable directly in a solid semiconductor, i.e., wound inductors, mechanically variable capacitors, and large values of capacitance. Where possible, an equivalent circuit which avoids the use of these is set up. Then, based upon the knowledge of available effects in semiconductor materials, a 3-dimensional model of the block structure to perform the same electronic function is developed. The

Fig. 7. Single-stage amplifier block, characteristics and equivalent circuit.





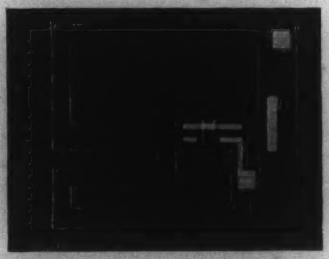


Fig. 8. Low-level Darlington amplifier block and characteristics. (Markers on block are spaced at 1/16 inch.)

model is fabricated using many of the techniques which are adapted from those which are common to the transistor industry. Among these are high-temperature diffusions of elements into the semiconductor crystal, oxide masking and mechanical masking, chemical and mechanical shaping, growth of surface oxide films, vacuum deposition of materials, alloying operations, etc. The use of photographic techniques in the production of very precise optical masks is extensive. Such masks are used in conjunction with some of the operations listed to yield finely detailed areas with high resolution.

Amplifiers. In a functional block of this functional category, one finds a wide range of terminal characteristics. A general classification might include amplifier parameters such as input and output impedance, gain—expressed in several possible ways—frequency response, dynamic level, etc. Other special attributes may involve electrical stability and temperature dependency. In order to demonstrate flexibility and adaptability of techniques which have been developed in molecular electronics, work on amplifiers has included audio, high-frequency, selective-frequency, and tunable types. Amplifiers with a wide range of input and output impedance have been fabricated. Input signal levels of a few microwatts to signal output levels of several watts have been handled successfully.

Transistorized amplifiers, of course, depend to a large extent upon the characteristics of the component transistor devices which are used. In functional amplifier blocks, over-all behavior is also determined to considerable degree by the characteristics of the active transistor regions which are built into the structure. Transistor triodes as three terminal devices may be connected in several possible ways to obtain amplifiers with various combinations of input and output parameters. The feasibility of many of such possibilities of transistor amplified staging in semiconductor material has been demonstrated. Resistances which are commonly employed for establishing transistor biases and operating points, resistances which serve to temperature-stabilize such operating points, and resistances which provide loads have been incorporated in many cases. Capacitance for coupling and by-passing purposes has been included in amplifier structures where the values required were reasonably small, up to 1,000 μμf. Higher values when fabricated as a biased p-n junction require semiconductor block areas which become disproportionately large. This becomes a problem particularly in audio amplifiers, where external capacitors sometimes are used. External capacitors of the same form factor as the semiconductor blocks may be laminated with these blocks and, in this way, miniaturization features are preserved.

1. *Single-Stage Amplifiers.* Functional amplifier blocks consisting of a single transistor area biased in a common-emitter operating mode have been constructed. The approximate equivalent circuit, as shown in Fig. 7, contains a voltage divider resistance network which fixes the base bias. An internal load resistance has been incorporated. Designed for low-level applications, the total block current may be only 2 milliamperes, with a 22½-volt supply. Frequency response is flat out to 3 to 4 mc; thus, this amplifier is suitable for use in video and r-f applications. A power gain in excess of 25 db is realized when operating between a source at 400 ohms and an external load of 3,000 ohms. Other amplifier blocks containing single transistor regions have been designed and fabricated to deliver output powers up to 1 watt at power gains of 30 db.

2. *Multistage Amplifiers.* The cascading of transistors

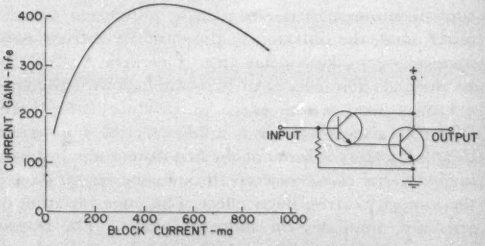
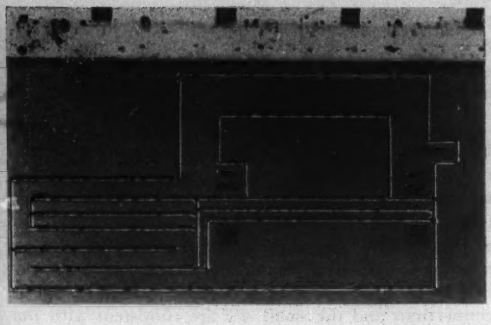


Fig. 9. High-level Darlington amplifier block and characteristics. (Block diameter is ½ inch.)



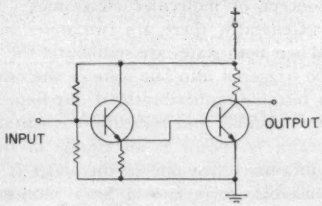


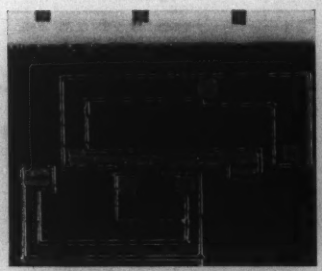
Fig. 10. Two-stage amplifier block, common-collector input. (Markers are spaced at 1/16 inch.)

in functional blocks, in order to provide amplifiers of higher gain or of modifiable input and output impedance, has resulted in several interesting designs. One of these is the Darlington connection which is particularly adaptable to fabrication since it allows a common collector region in the block. Fig. 8 presents the equivalent circuit and the constructed semiconductor block version designed to operate at low signal levels. All resistances shown have been included on the block to produce a completely self-contained amplifier requiring only an external bias source. Physical dimensions of the silicon wafer shown are 0.150 by 0.250 by 0.004 inch. Input impedances up to 150,000 ohms have been obtained; output impedances have averaged 2,000 ohms for the units which have been built. Power gains of about 30 db are obtainable with some blocks, giving essentially flat frequency response to 1 to 2 mc. Of particular use is the high input impedance in applications in which loading effects on the preceding stage must be minimized.

The Darlington cascaded connection has also been utilized in a very-high-level amplifier constructed on a single-crystal wafer, as shown in Fig. 9 along with the approximate equivalent circuit. Possible applications for this amplifier include use as high-power audio output or as a power amplifier which can directly control mechanical devices such as servomotors. Output current swings up to 1 ampere are available at current gains of about 500. A temperature stabilization resistor is built in as shown; load resistance is external.

For amplifier applications in which the higher input impedance as available from a common-collector input is desirable, the configuration shown in Fig. 10 has been designed. The operating point of the second transistor is critically dependent upon that of the first, and resistance adjustments are somewhat difficult where the cascade is built into a single block. Input impedances of about 5,000 ohms were obtained in the experimental units. For greatest gain–bandwidth product, the arragnement shown in Fig. 11 has been used. Essentially, the equivalent circuit is that of two directly coupled common-emitter stages with a feedback loop around the two stages through a resistor. This amplifier is ideally suited for wide-band video applications. Input impedances of 500 ohms with output of 3,000 ohms have been measured with reasonably flat frequency response to 2 mc. Where very high input impedances are necessary, amplifiers which resort to the field effect or unipolar transistor have been developed. A resistive area which is modulated by an input signal controls the base current flowing into the base region of a bipolar transistor. The name "Unibi" has been attached to this particular type of amplifier, which is shown in Fig. 12. It features a very high input impedance usually associated with such field-effect devices. (Up to 1 megohm has been measured.) The field-effect region also serves as a very effective means for directly cascading several of such amplifier blocks without concern for impedance matching or for d-c decoupling.

3. *Selective Frequency Amplifiers.* Mention has already been made of the distributed *R-C* networks which have been fabricated in semiconductor materials. These networks use either diffused or uniform crystal resistive layers and a capacitance which is associated with inversely biased p-n junction layers. The network that is described in Fig. 5(B) and (C) has phase-shifting properties. It has been possible to combine semiconductor network of this nature into a feedback loop around the single-stage amplifier described in Fig. 7 to produce a selective frequency bandpass amplifier. The equivalent circuit of this structure is as shown in Fig. 13. Values of Q as high as 400 for the amplifiers constructed have been measured. Amplifier Q may be adjusted over a wide range by varying amplifier gain or by inserting a lumped resistance in series with the network capacitance as in Fig. 6(A). Stability of these amplifiers was



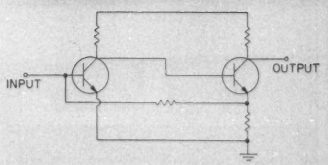
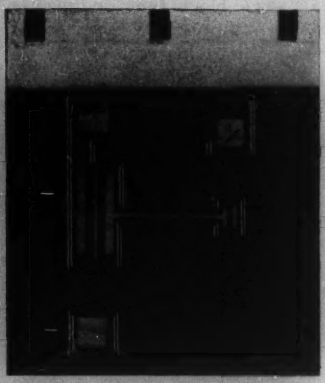


Fig. 11. Two-stage amplifier block, common-emitter cascade. (Markers are spaced at 1/16 inch.)



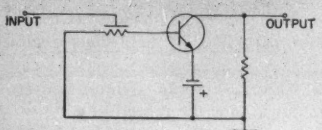


Fig. 12. Unibi amplifier and equivalent circuit. (Markers are spaced at 1/16 inch.)

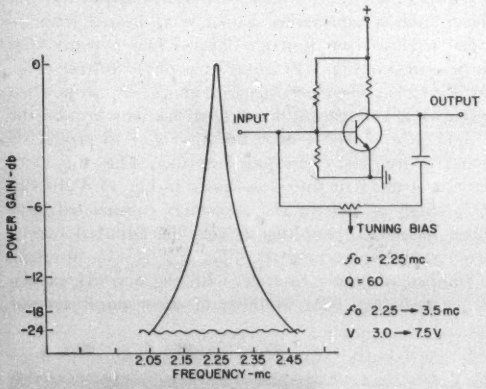


Fig. 13. Selective frequency amplifier, equivalent circuit, and characteristic.

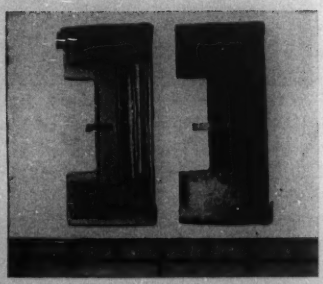


Fig. 14. Astable multivibrator functional block.

found to be unusually good. Tuning of these amplifiers may be accomplished by applying a small bias to the filter. Tuning ranges of 3 to 1 were shown to be possible.

Multivibrator Functional Blocks. Multivibrators have been built within a single block of semiconductor material. Bistable, astable, and monostable multivibrators have all been constructed and demonstrated. The multivibrators constructed have no soldered connections between the different regions within the block and a minimum of external connections for the proper functioning of the multivibrators. The minimization of connections and the small size are consistent with the concept of molecular electronics.

Generally, there are two states in a multivibrator. When both states are stable and the multivibrator can be triggered into one state or the other, it is known as a bistable multivibrator or flip-flop. When both states are unstable and oscillation is sustained, the multivibrator is known as an astable or free-running multivibrator. When one of the states is stable and one is unstable, it is known as a monostable or one-shot multivibrator.

Certain multilayer structures have also been used to produce the proper action. The dissipative region is made of the bulk semiconductor material. It provides sufficient resistance to be used as a load or to form biasing paths for the active regions. The storage of energy can be accomplished by the use of reverse-biased junctions. Such regions are used to speed up the switching time of the multivibrator or form the time base for the astable and monostable multivibrators.

1. *Analog Cross-Coupled Structures.*

Astable multivibrator—This device can be made in a monolithic block (Fig. 14) as an analog of the conventional cross-coupled multivibrator (Fig. 15). The block is built on a diffused silicon wafer with two layers of opposite conductivities. The diffused structure is chosen to permit the formation of high-resistivity dissipation regions in the diffused n-layer. Diffused structures also increase the frequency response of the active regions and hence of the multivibrator. Foils containing proper amounts of doping agents are alloyed into the wafer to form the common emitter and to provide ohmic contacts, and grooves are etched through one conductivity layer to provide isolation between regions where desired. The tabs are the points where electrical contacts for the inputs, the outputs, and the power supply are made. The arrangement of regions and foils eliminates all unnecessary lead wires and soldered contacts. There are only three terminals; one for the output, one for the ground, and one for the positive supply voltage. The area of the block is determined largely by the required capacitance of the reverse-biased junctions, which in turn depends on the desired oscillating frequency of the multivibrator. The output waveform of the astable multivibrator is shown in Fig. 16. Multivibrators of this type have been fabricated in the range of 20 to 500 kc.

Bistable multivibrator—Bistable multivibrators can also be made by cross-coupling two active regions. An equivalent circuit of this type of multivibrator is shown in Fig. 17. An actual bistable multivibrator functional block is shown in Fig. 18, placed next to a conventional multivibrator. The diffused silicon wafer, alloying foils, and etched grooves are similar to those used in the analog astable multivibrator. The waveforms of a typical flip-flop are shown in Fig. 19. This flip-flop was triggered at the rate of 60 cps and 500 kc. Note that there is very little difference in performance at 0, 25, and 50 C.

Monostable multivibrator—A monostable multivibrator with an equivalent circuit as shown in Fig. 20 has also been fabricated. The appearance and the fabrication are similar to that of the analog cross-coupled astable multivibrator. The waveform of such a multivibrator is shown in Fig. 21.

2. *Four-layer structures.* The required regeneration for multivibrator action can also be obtained by cascading a p-n-p active region to an n-p-n active region. By overlapped connection of two layers in each region, a four-layer structure is formed. The 4-layer structure exhibits a negative resistance V–I characteristic (Fig. 22), which can be used in conjunction with a load to produce bistable multivibrator action. The equivalent circuit of such a multivibrator is shown at the top of Fig. 22. The structure may be triggered into high or low conduction as indicated by the curve in Fig. 22. The output waveform is shown in Fig. 23.

In addition to the conventional design considerations of a multivibrator, there are many other aspects to consider in a functional electronic block. In designing functional electronic blocks, it should be kept in mind that the bulk resistivity is temperature sensitive. However, a monolithic block has a relatively uniform temperature. Thus, the resistance of the different regions will vary by the same percentage. This feature can be utilized to stabilize the performance of a multivibrator. For instance, in the analog bistable multivibrator (Fig. 17) the output ON voltages, the OFF voltage, and the switching times are functions of R_C/R_B, (the ON voltage and the switching times determined by the ratio of the collector current to the base current which in turn depends on R_C/R_B). Any variations in temperature will change the values of R_C and R_B but not the ratio of R_C/R_B appreciably. Therefore, the performance is not severely affected. This is evidenced by the lack of difference in the waveforms (Fig. 19) taken at 0, 25, and 50 C.

Functional Electronic Switches. Functional electronic blocks providing the action of multiposition switches may be designed around 3-region transistor-like performance or 4-region n-p-n-p bistable switches.

Of course, multiposition switches may be designed by making multiple switching elements on a single semiconductor block. For example, it is possible to fabricate groups of transistors or 4-region switches on a single semiconductor wafer. These types of switches

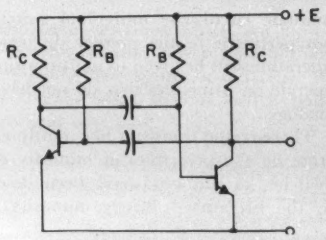


Fig. 15. Conventional cross-coupled multivibrator.

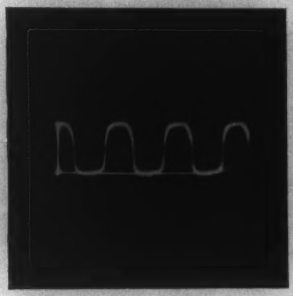


Fig. 16. Waveform of astable multivibrator block; 1 volt per division, 5 seconds per division.

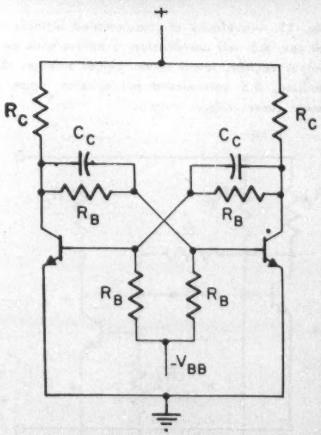


Fig. 17. Equivalent circuit of cross-coupled bistable multivibrator.

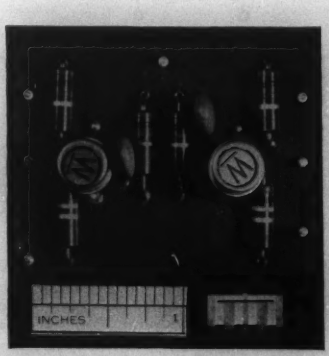


Fig. 18. Cross-coupled bistable multivibrator block.

simulate circuitwise individual switch arrays and are not pertinent to the present discussion. Rather, consideration will be given to multiposition switches which operate on principles that do not have direct circuitry analogy.

Three-region transistor-like multiposition switches operate on the principles of minority carrier deflection. Switches of this type have been described previously in the literature.[6] Briefly, minority carriers injected by the emitter are deflected by a transverse base field established by the presence of two or more base contacts, causing the minority carriers to diffuse preferentially towards one of a plurality of collectors. Multiposition switches of this type are transistor-like in their behavior. That is, they require continuous application of a switching signal to remain in a particular switch position. A single-pole double-throw principle is shown in Fig. 24.

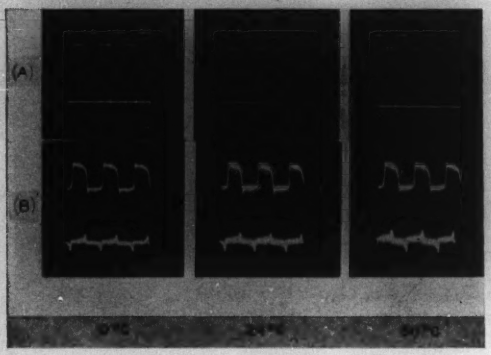


Fig. 19. Waveforms of cross-coupled bistable multivibrator block. (A) 60 cps, 0.5 volt per division, 5 milliseconds per division; upper curve: output voltage; lower curve: trigger voltage. (B) 500 kc, 0.2 volt per division, 0.5 microsecond per division; upper curve: output voltage; lower curve: trigger voltage.

1. *Bistable Switches.* The other switching principle mentioned is based on the 4-region n-p-n-p bistable switch. Multiposition switches based on 4-region bistable switches may also be of the 2-terminal or 3-terminal type. Extensive effort has gone in the design and development of multiposition switches based on 4-region switches. The action of 4-region bistable switches is dependent on which of the regions are common to the various switch positions as well as the location of the base contact.

When multiposition bistable switches are fabricated with only one region common to every switch element as shown in Fig. 25, individual switches result. Consideration of these switches is no different than for a wired independent switch array.

When multiposition switches are fabricated with two regions in common, as in Fig. 26(A), the switch positions function independently as 2-terminal type switches. If the common-emitter and common-base connection are utilized, the multiposition switch positions may be operated as the dependent 3-terminal type switches of Fig. 26(B). Alternately, through the use of the separated emitter and base regions, this type of switch may also be operated as independent 3-terminal type switches; see Fig. 26(C).

An interesting mode of operation occurs for the switches of Fig. 27 with the "three regions" in common. Such switches are independent in the OFF or high-impedance state but when one position turns ON all positions go into the low-impedance or ON state. Thus, the performance of this structure is somewhat similar to a logic OR. However, when attempting to turn OFF an individual switch element of this type of switch, it is necessary to turn OFF every switch position.

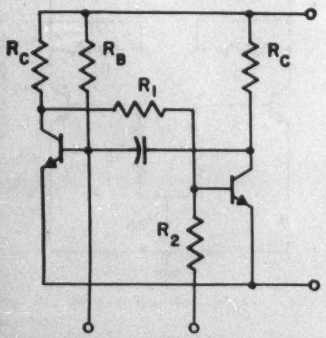


Fig. 20. Equivalent circuit of monostable multivibrator.

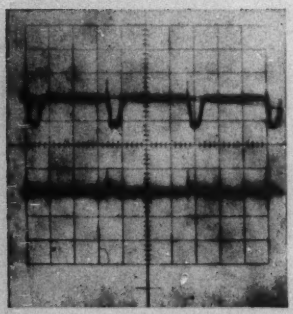


Fig. 21. Waveform of monostable multivibrator block.

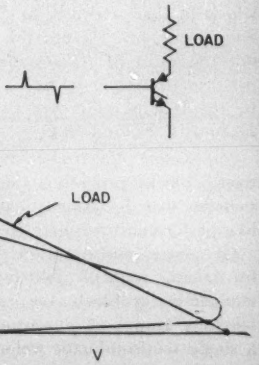


Fig. 22. (Top) Equivalent circuit of 4-layer multivibrator. (Bottom) 4-layer structure characteristic.

In addition to the switch type described, modifications in performance result if isolation is provided into, but not through, one of the regions, as shown in Fig. 28. For switches of this type, the distance between switch positions may be extremely important. The bistable switches just described were fabricated from both germanium and silicon. Most of the germanium multiposition switches were fabricated on dendritic strips. These long strips of single crystal material are very convenient for fabricating multiple-switch structures. They make possible, with no crystal preparation prior to diffusion, the type of switch shown in Fig. 29, which is a 50-position bistable switch. Each element is p-n-p-n where two of the four regions are common to all positions. The 50 positions are shaped on a 1-inch strip of germanium dendrite.

Multiple switches of this type can be very uniform in characteristics from element to element. The uniformity of thickness and resistivity of the germanium dendrite and the high degree of perfection of the dendrite surface are excellent for the fabrication of a multiple-type device.

2. *Commutating-Type Switches.* The switches described earlier do not make use, in their operation, of nonuniformities of minority carriers in the base regions of the multiposition switches. Fairly sophisticated multiposition switches which do not require a control for every controlled position, which can be used as commutating-type structures, and which have certain other uses as counters, registers, and other commutator functions, may be designed using unbalanced minority carriers in the base region. One such structure is shown in Fig. 30. Operation commences with one switch position in its low impedance or ON state while all other elements are in a high impedance or OFF state. By the application of a transverse base voltage, it is possible to turn on other switch elements. Structures have also been described which are multiposition switches that also utilize uneven distributions of minority carriers in the base region or difference in bias across a base region when various switch positions are turned ON and OFF.

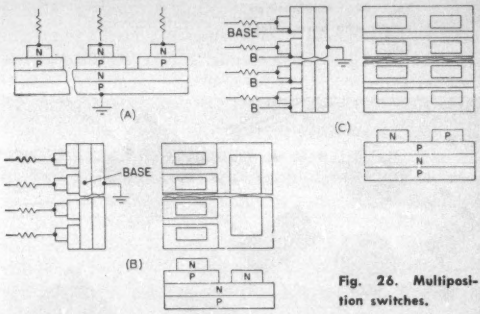


Fig. 26. Multiposition switches.

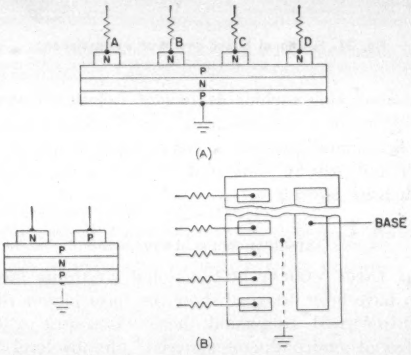
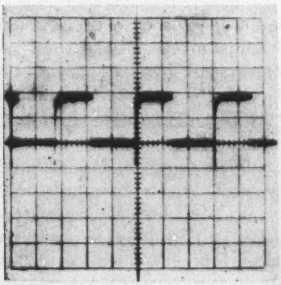


Fig. 27. Multiposition switches with three common regions.

Fig. 23. Waveform of 4-layer multivibrator block.



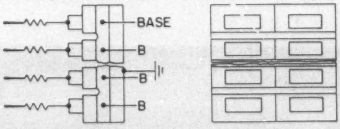
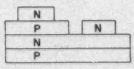


Fig. 28. Multiposition switch, partially isolated.



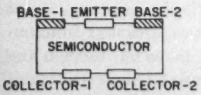
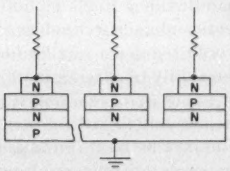


Fig. 24 (above). Single-pole double-throw switch. Fig. 25 (*right*). Independent multiposition switch.



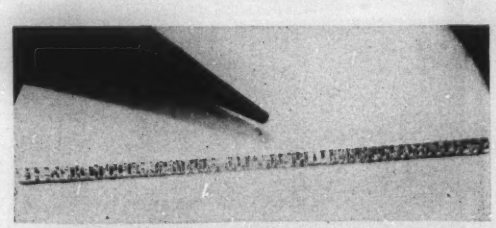


Fig. 29. Multiposition switch on germanium dendrite.

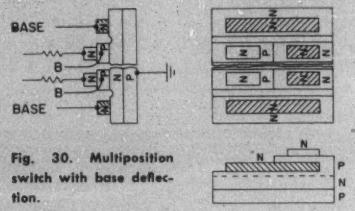


Fig. 30. Multiposition switch with base deflection.

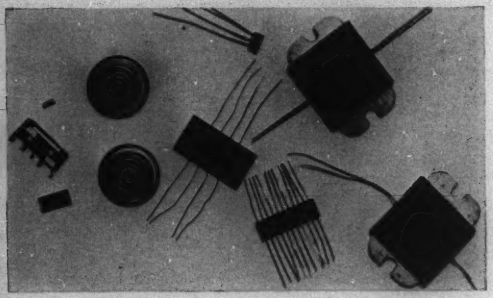


Fig. 31. Functional blocks and their encapsulation.

By combining various degrees of isolation between the regions of a multiposition switch with transverse base fields, multiposition switches with modes of behavior not readily simulated by independent wired switches are possible.

SYSTEM INTEGRATION

THE LARGE VARIETY of functional electronic blocks which have been designed show the form factors illustrated in Fig. 31. In general, the blocks consist of thin platelets of semiconductor material. The low-level amplifiers described here have been constructed with a 0.004-inch thickness of silicon. Because of the fragile nature of the material in such thin sections, it is desirable to process these blocks, at least in the later phases, upon a supporting substrate. In this way, handling is facilitated and the substrate can subsequently be made part of the encapsulating envelope.

Fig. 32 shows a 2-stage amplifier block which is thus supported, and illustrates how the leads are brought out from the block for external connections. Wires of about 0.002-inch diameter are bonded to the appropriate points on the block and to the larger external leads. For assembly of functional blocks into a large module, which would be later provided with a hermetic housing, only an interim protective coating may be applied to the block. Where the functional block itself is to be hermetically sealed, ceramic–metal and glass–metal encapsulations are being developed. Fig. 33 illustrates one of these. A shallow ceramic box is constructed with a plurality of metallic connectors which feed through one or more sides of the enclosure. A cover is soldered to the metallized top surfaces. The semiconductor element is fastened to the bottom of the box for heat dissipation and for equalization of temperature over the surface area of the block. The package size for a 2-stage amplifier is 0.375 by 0.375 by 0.030 inch. Total dissipation for this block, at present, is being limited to 200 milliwatts. Certain high-level amplifiers shown in Fig. 31 have required larger packages and have also been provided with a heat-dissipating metal plate which forms one face of the package.

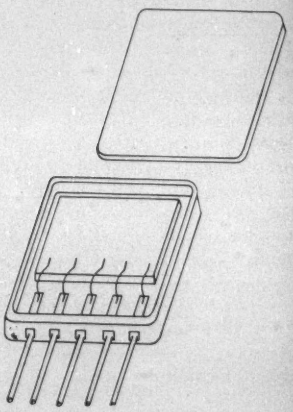


Fig. 33. Ceramic case for hermetically sealed block.

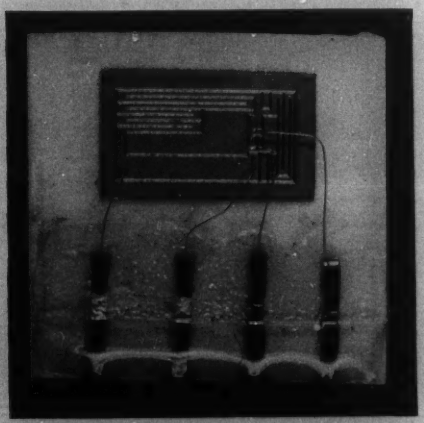


Fig. 32. Unencapsulated amplifier.

The 0.375- by 0.375-inch package represents the amount of functional structure (low-level circuitry) which can now be conveniently and economically handled in a single monolith with the present state of semiconductor technology. Where a particular function would require a smaller block of material, there is the possibility of placing more than one of these functions in a package of this size. It is also anticipated that when greater control over processing is achieved, more structure may be built into a single section of semiconductor materials, thereby resulting in larger package sizes.

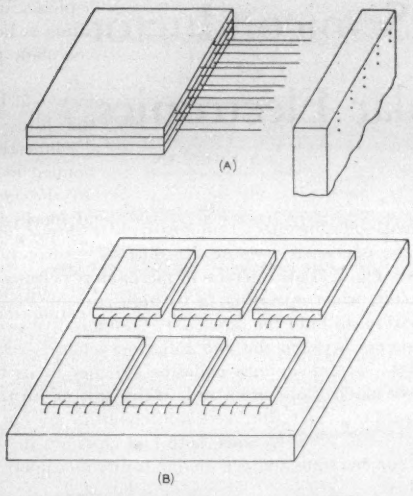


Fig. 34. Functional block interconnections.

The unit functional packages may be arranged for interconnection by vertical stacking, as shown in Fig. 34(A) or in the manner pictured in Fig. 34(B). With either configuration, the external leads would terminate in thin boards which would provide power and coupling for the array of blocks. The arrangement of Fig. 34(B) would permit better heat dissipation, whereas the arrangement of Fig. 34(A) gives the higher packing density. A group of functional blocks with its board would constitute a circuit module. Several modules might then be integrated to form a complex system.

SUMMARY

THE FEASIBILITY of performing many electronic functions in solid semiconductor materials has been demonstrated. Functional blocks have been fabricated utilizing many of the presently known phenomena in solid semiconductors. In the course of this work, it has been found that many configurations developed have exhibited performances which can be duplicated only with greater difficulty by conventional circuitry means. The molecular electronics approach will, no doubt, lead to many new concepts in the realization of electronic functions. Reduction in size and weight of electronic systems will be limited only by heat dissipation requirements. Reliability should be considerably enhanced by the elimination of a large portion of conventional connections and through the elimination of much of the exposed surface areas of components of conventional circuitry.

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Reactor Control System for Antarctica

The instrumentation and control system for the *PM-3A* nuclear reactor to be installed at McMurdo Sound, in Antarctica, is shown just before it was crated and shipped recently from General Dynamics/Electronics, Rochester, N. Y., to The Martin Company, Baltimore, Md., which is building the reactor.

This nuclear instrumentation system is completely transistorized, and incorporates an exclusive General Dynamics/Electronics 7-channel system that is capable of measuring and controlling the neutron flux in the reactor from cold start-up to approximately 150 per cent of rated power output.

Among the important features are automatic self-checking circuits which will inform the operator immediately if a malfunction should develop in the instrumentation system, and will pinpoint its location as well. The central control console provides facilities that enable one man to monitor and operate the 1,500-kw nuclear power plant.

Multiple-Collector Semiconductor Devices in Molecular Electronics

D. P. KENNEDY S. GILMAN

A theoretical analysis is presented on the operation of a computer logic component exhibiting current commutation between two hook collectors. A quantitative theory is established for the current-multiplying hook collector and for many factors contributing to the interaction between such collectors. Appropriate equations are presented in graphical form throughout a range of physical and geometrical parameters encountered in the design of a typical 2-collector structure.

INTERACTION mechanisms between current-multiplying hook collectors can result in a commutation of their respective collector currents. This principle of operation, when applied to the design of semiconductor devices, provides active computer components with greater logic power than that available from conventional transistors. Two hook collectors, for example, interacting upon the same emitter junction, will generate the logic function of binary full addition.[1] Further, it can be shown [2,3] this 2-collector device is a basic building block for the logical design of large-scale digital computers. Application of hook collector interaction to the design of unique semiconductor devices represents a fundamental approach to molecular electronics; basic physical mechanisms are used to satisfy specific computer logic requirements.

Mathematical computations required for the theoretical design of this semiconductor device must be conducted upon a high-speed electronic computer. To facilitate such computations, computer programs are available, upon request, for the numerical evaluation of design equations presented in this article.

THE 2-COLLECTOR SWITCHING DEVICE

FIG. 1 ILLUSTRATES the semiconductor device considered in this analysis. Two cylindrical hook collectors are located upon one side of a large, cylindrical, emitter junction. Electrical contact is made to four locations upon this structure: the large area emitter region, the common—or base—region, and the two hook emitter regions. The base region ohmic contact is a metallic ring located near the periphery of this solid cylinder. An external reverse biasing potential V_{bc}, is applied to each hook collector junction through individual load resistors R_{L1} and R_{L2}. Further, a forward bias V_{be} is applied to the large area emitter junction through a series resistance R_e; this resistance is assumed to be of sufficient magnitude to approximate a constant current source for the emitter.

Hook collector interaction is easily identified throughout the operation cycle of a 2-collector semiconductor device, Fig. 2. This interaction mechanism permits one collector, when operating in its high current mode of operation, to hold the other OFF. Commutative switching occurs between the two collectors when $I_e = I_{e2}$; the low current—or OFF—collector switches to its high current mode of operation and, in the process, turns the other collector OFF. Interaction mechanisms are not observed when $I_e > I_{e3}$ since both collectors are in their high current state and are unable to interact upon one another.

The 2-collector semiconductor device represents an important, but difficult, approach to the field of molecular electronics. Physical mechanisms within this device are used to obtain a complex set of electrical characteristics (Fig. 2) that would otherwise require an extensive number of conventional transistors, resistors, capacitors, etc. This technique of logic component design requires a degree of control not presently available in the semiconductor field; such control must result in reproducible electrical characteristics of the type illustrated.

THE HOOK COLLECTOR[4]

COMMUTATION between two hook collectors is a direct result of the current multiplication encountered in this multiple-layer semiconductor structure. A minority carrier (hole) current J_{pc} enters the hook collector region from the base (Fig. 3); this current is caused by a forward bias upon the large area emitter junction. An accumulation of electrostatic charge in the hook collector region results in a forward bias upon the hook emitter junction thereby producing a minority carrier (electron) current J_{ne} within the hook collector region. Steady-state operation of this semiconductor device is achieved when

$$I_{nc} = \beta_T I_{pc} \tag{1}$$

The parameter β_T, equation 1, is equivalent to the common emitter current gain of a conventional transistor,

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The authors would like to acknowledge the invaluable assistance of their associates at IBM. In particular, they wish to thank R. F. Rutz, inventor of the 2-collector device, for many stimulating discussions. Further, an extensive amount of credit is due F. Goth, R. A. Kuchenbecker, and B. Holman. Goth and Kuchenbecker developed the IBM 704 computer programs used extensively for the theoretical analysis of devices, while Holman constructed a large number of the experimental 2-collector units which were used throughout this investigation.

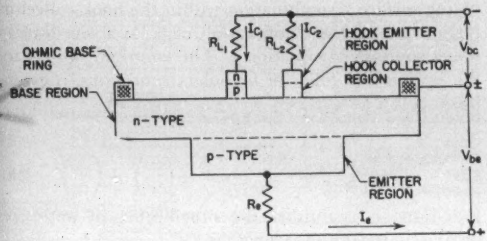

Fig. 1. A 2-collector semiconductor device.

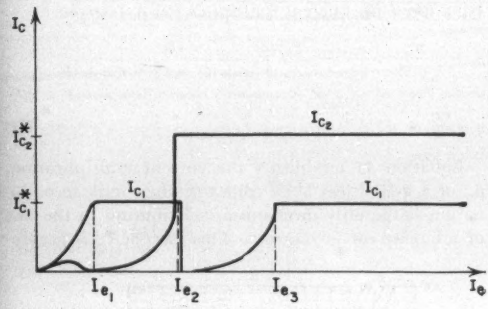

Fig. 2. Illustrative operation cycle of a 2-collector semiconductor device.

$$\beta_T = \frac{\alpha}{1-\alpha} \tag{2}$$

Separation of the mechanisms contributing to hook collector current multiplication, β_T, results in a significant simplification in the analysis and design of this structure. Such separation reduces β_T to the form

$$\frac{1}{\beta_T} = \frac{1}{\beta_s} + \frac{1}{\beta_r} + \frac{1}{\beta_\gamma} \tag{3}$$

where β_s, β_r, and β_γ, respectively, are the magnitudes of current multiplication resulting from the individual mechanisms of surface recombination in the hook collector region, bulk recombination in the hook collector region, and minority carrier injection efficiency of the hook emitter junction.

The parameter β_s, equation 3, represents the current multiplication of a hook collector containing an ideal emitter junction ($\gamma = 1$) and no bulk recombination within the hook collector region ($\tau_n = \infty$). Calculation of β_s, therefore, is accomplished by determining the minority carrier transport efficiency, B_s, of a solid cylinder—the hook collector region—assuming a surface recombination velocity of *(s)*. A complicating factor in this analysis results from an axial distribution of donor impurities in the hook collector region which is introduced by the technique of diffusion. This impurity distribution causes an electrostatic potential gradient enhancing minority carrier current from the emitter to the collector junction. A simplification has been used in which the hook collector electric field is approximated by one of constant magnitude,[5] E_z, parallel to the z-axis, and directed to the hook emitter junction.

The minority carrier transport efficiency, B_s, of the hook collector region, Fig. 3, is established through a solution of the continuity equation

$$0 = \frac{\partial^2 n_p}{\partial r^2} + \frac{1}{r}\frac{\partial n_p}{\partial r} + \frac{\partial^2 n_p}{\partial z^2} + \epsilon \frac{\partial n_p}{\partial z} - \frac{n_p}{L_p{}^2} \qquad \epsilon = \frac{qE_z}{kT} \tag{4}$$

in which an infinite minority carrier lifetime is assumed. This solution must also satisfy the multitude of boundary conditions imposed by practical considerations. A minority carrier recombination velocity of *(s)* is to exist at the outer surface ($r = a$; $0 < z < w$) of this cylindrical hook collector region. Furthermore, a minority carrier source—the emitter junction—is approximated by a surface of constant minority carrier density, n_{pe}, at one end of this solid cylinder ($0 < r < a$; $z = w$), while at the other end ($0 < r < a$; $z = 0$) the collector junction is a surface containing no excess minority carriers.

A solution of this boundary value problem yields the excess minority carrier distribution equation

$$n_p(r;z) = 2n_{pe}\, e^{\frac{\epsilon(w-z)}{2}} \sum_{m=1}^{\infty} \frac{\sinh\left(\delta_m \frac{z}{a}\right)}{\alpha_m \sinh\left(\delta_m \frac{w}{a}\right)} \left\{ \frac{J_1(\alpha_m)\, J_0\left(\alpha_m \frac{r}{a}\right)}{J_0{}^2(\alpha_m) + J_1{}^2(\alpha_m)} \right\} \tag{5}$$

where

$$\text{(a)} \quad \alpha_m J_1(\alpha_m) - \frac{s\,a}{D_p} J_o(\alpha_m) = 0 \tag{6}$$

$$\text{(b)} \quad \delta_m{}^2 = \left(\frac{\epsilon a}{2}\right)^2 + \alpha_m{}^2$$

The summation of equation 5 is conducted over ascending roots of equation 6a; there are an infinite number of such roots for each assumed magnitude of surface recombination velocity *s*.

The axially directed component of minority carrier current, $J_{nz}(r;z)$, within this solid cylinder is given by

$$J_{nz}(r;z) = -qD_p \frac{\partial n_p}{\partial z} - q\mu p\, n_p E_z \tag{7}$$

A radial integration of this expression, equation 7, yields the total electron current at the emitter junction

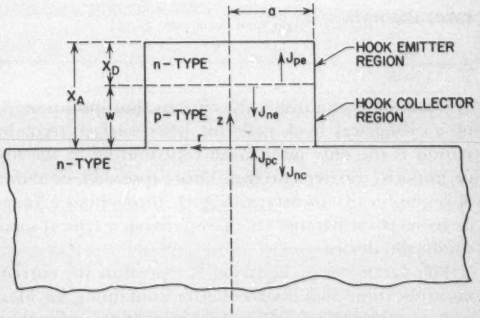

Fig. 3. Analytical model of a cylindrical hook collector.

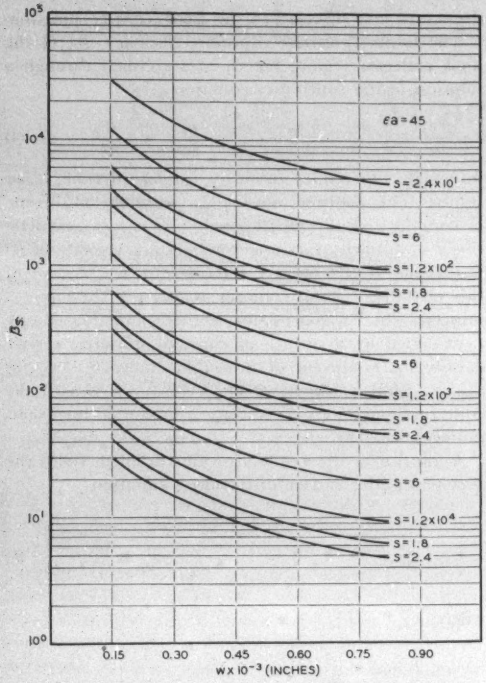

Fig. 4. Current multiplication parameter β_s for a typical hook collection.

$(z = w)$ and also at the collector junction $(z = 0)$. Substituting equation 5 into equation 7, and performing the required integration, yields the minority carrier transport efficiency

$$B_s = \frac{I_{nc}}{I_{ne}} = e^{\frac{\epsilon w}{2}} \frac{\sum_{m=1}^{\infty} \frac{\delta_m J_1^2(\alpha_m)}{\alpha_m^2 [J_0^2(\alpha_m) + J_1^2(\alpha_m)] \sinh\left(\delta_m \frac{w}{a}\right)}}{\sum_{m=1}^{\infty} \frac{\left[\delta_m \operatorname{ctnh}\left(\delta_m \frac{w}{a}\right) + \frac{\epsilon a}{2}\right] J_1^2(\alpha_m)}{\alpha_m^2 [J_0^2(\alpha_m) + J_1^2(\alpha_m)]}} \tag{8}$$

If we now assume that an ideal hook emitter junction exists within this semiconductor device, equation 2 takes the form

$$\beta_s = \frac{B_s}{1 - B_s} \tag{9}$$

Equation 9 establishes the current multiplication, β_s, of a cylindrical hook collector when surface recombination is the only mechanism contributing to the loss of minority carrier current. This expression, equation 9, is graphically illustrated, Fig. 4, throughout a range of geometrical parameters characterizing a typical semiconductor device.

The parameter β_r, equation 3, represents the current multiplication of a hook collector containing an ideal emitter junction $(\gamma = 1)$ and no surface recombination current within the hook collector region $(s = 0)$. Eliminating surface recombination within the hook collector region reduces the computation of β_r to a one-dimensional solution of equation 4. This solution, subject to the emitter and collector boundary conditions, is given by

$$n_p(z) = n_{pe} \frac{\sinh\left(\delta \frac{z}{w}\right)}{\sinh(\delta)} e^{\frac{\epsilon(w-z)}{2}} \qquad \delta^2 = \left(\frac{\epsilon w}{2}\right)^2 + \left(\frac{w}{L_n}\right)^2 \tag{10}$$

Equation 10 establishes the distribution of minority carriers (electrons) throughout this one-dimensional hook collector region which is assumed to have a minority carrier diffusion length of L_n. From equation 2 and equation 7 the current multiplication β_r is given by

$$\beta_r = \frac{B_r}{1 - B_r} = \frac{I_{nc}}{I_{ne} - I_{nc}} = \frac{\delta e^{\eta}}{\delta [\cosh(\delta) - e^{\eta}] + \eta \sinh(\delta)}$$

$$\eta = \frac{\epsilon w}{2} \tag{11}$$

Equation 11 establishes the current multiplication, β_r, of a cylindrical hook collector when bulk recombination is the only mechanism contributing to the loss of minority carrier current. This parameter is graphi-

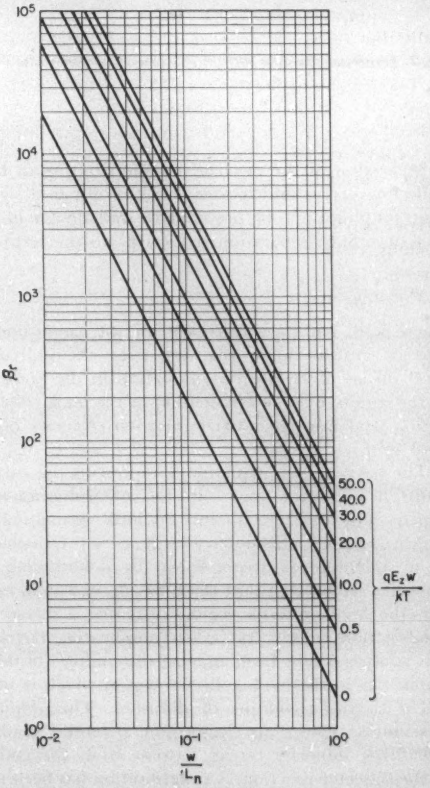

Fig. 5. Current multiplication parameter β_r for a cylindrical hook collector.

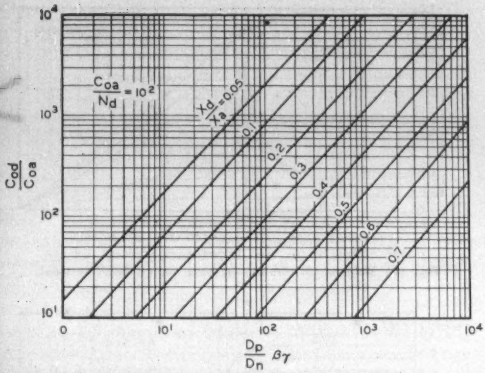

Fig. 6. Current multiplication parameter β_γ for a typical hook collector.

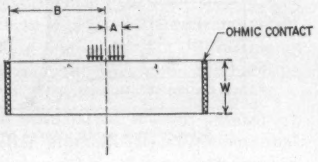

Fig. 7. Analytical model of solid cylinder base region.

cally illustrated (Fig. 5) throughout a range of physical and geometrical parameters suited to most situations.

The last parameter required in the determination of hook collector current multiplication, equation 3, is β_γ. This term represents the current multiplication within a device having an ideal minority carrier transport efficiency throughout its hook collector region ($\tau_n = \infty$; $s = 0$). The hook emitter junction introduces a minority carrier current, J_{pe}, into the n-type hook emitter region, thereby reducing the injection efficiency, γ, of this structure.

Previous authors[6] have established the minority carrier injection efficiency of the diffused emitter junction. Assuming an impurity distribution, $N(x)$, throughout the hook emitter and hook collector regions, where

$$N(x) = C_{oa}\, erfc\left(\frac{x}{L_a}\right) + C_{od}\, erfc\left(\frac{x}{L_d}\right) \tag{12}$$

the emitter junction currents J_{pe} and J_{ne} are given by

$$\text{(a)}\quad J_{pe} = qn_i^2\, D_p \frac{e^{\frac{qv}{kT}} - 1}{\int_e N(x)dx}$$

$$\text{(b)}\quad J_{ne} = qn_i^2\, Dn \frac{e^{\frac{qv}{kT}} - 1}{\int_c N(x)dx} \tag{13}$$

The integrations of equations 13 are conducted across the hook emitter and hook collector regions of this semiconductor device. From equation 2 and equations 13, the current multiplication parameter β_γ is given by the expression

$$\beta_\gamma = \frac{\gamma}{1-\gamma} = \frac{J_{ne}}{J_{pe}} = \frac{D_n \int_e N(x)dx}{D_p \int_c N(x)dx} \tag{14}$$

Equation 14 establishes the parameter β_γ required in the computation of total curent multiplication of the cylindrical hook collector. This expression is illustrated in graphical form, Fig. 6, throughout a range of geometrical parameters characterizing a typical semiconductor device.

BASE REGION ELECTROSTATIC POTENTIAL[7]

THE UNIQUE electrical properties of a 2-collector semiconductor device (Fig. 2) are caused by the mechanism of current multiplication within each hook collector. From equation 1, a majority carrier current, I_{nc}, appears at the hook collector junctions (Fig. 3) with a magnitude proportional to the hole current I_{pc} entering from the base. This base region electron current and its associated electrostatic potential introduce an additional biasing voltage upon the emitter junction, thereby causing a radial distribution of minority carrier (hole) current throughout the structure. From such a mechanism of operation, one hook collector can eliminate all minority carrier current to another, thus yielding the observed commutation action.

Analytical investigation of the base region potential has been conducted upon a solid cylinder which approximates the base of a 2-collector device (Fig. 7). A

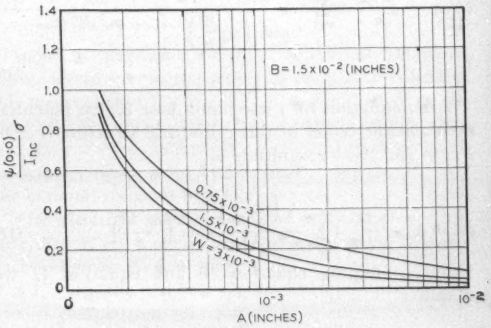

Fig. 8. Maximum base region voltage.

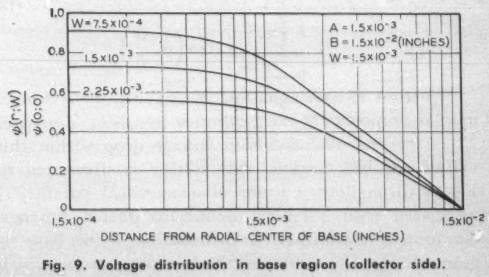

Fig. 9. Voltage distribution in base region (collector side).

single hook collector is symmetrically located at one end of this model, thereby reducing the structure to two spatial variables; analytical simplifications resulting from such approximation methods greatly outweigh small errors caused by this hook collector displacement. Furthermore, the ohmic base ring (Fig. 1) has been approximated by a surface of constant potential at the periphery of this solid cylinder. The base region width, in most practical semiconductor devices, is sufficiently narrow to permit characterization of an ohmic base ring (Fig. 1) by a constant potential surface at ($r = B$; $0 < x < w$).

The base region electrostatic potential, $\psi\ (r;z)$, is established by a solution of Laplace's equation

$$0 = \frac{\partial^2 \psi}{\partial r^2} + \frac{1}{r}\frac{\partial \psi}{\partial r} + \frac{\partial^2 \psi}{\partial z^2} \tag{15}$$

in which circular symmetry has been assumed. This solution must also satisfy the many boundary conditions imposed by practical considerations. A constant potential surface is used to characterize an assumed ohmic contact at the outer cylinder wall ($r = B$; $0 < z < w$). Further, a current source for this cylindrical structure—the hook collector junction—has been approximated by a region of constant current density J_{no} at one end ($0 < r < A$; $z = 0$).

A solution of this boundary value problem is given by the expression

$$\psi(r;z) = -\frac{2\,J_{nc}}{\sigma} A \sum_{n=1}^{\infty} \frac{\cosh\left[\frac{\alpha_n}{B}(W-z)\right]}{\sinh\left(\alpha_n \frac{W}{B}\right)} \left\{ \frac{J_1\left(\alpha_n \frac{A}{B}\right) Jo\left(\alpha_n \frac{r}{B}\right)}{\alpha_n^2\, J_1^2\,(\alpha_n)} \right\} \tag{16}$$

From equation 16, a maximum base region potential occurs at the center of this cylindrical structure ($r = 0$; $z = 0$) and has a magnitude of

$$\psi(0;0) = -\frac{2\,J_{nc}}{\sigma} A \sum_{n=1}^{\infty} \frac{J_1\left(\alpha_n \frac{A}{B}\right)}{\alpha_n^2\, J_1^2\,(\alpha_n)} \operatorname{ctnh}\left(\alpha_n \frac{W}{B}\right) \tag{17}$$

Upon combining equation 16 and equation 17 we obtain

$$\frac{\psi(r;z)}{\psi(0;0)} = \frac{\sum_{n=1}^{\infty} \frac{\cosh\left[\frac{\alpha_n}{B}(W-z)\right]}{\sinh\left(\alpha_n \frac{W}{B}\right)} \left\{ \frac{J_1\left(\alpha_n \frac{A}{B}\right) J_0\left(\alpha_n \frac{r}{B}\right)}{\alpha_n^2\, J_1^2\,(\alpha_n)} \right\}}{\sum_{n=1}^{\infty} \frac{J_1\left(\alpha_n \frac{A}{B}\right)}{\alpha_n^2\, J_1^2\,(\alpha_n)} \operatorname{ctnh}\left(\alpha_n \frac{W}{B}\right)} \tag{18}$$

Equation 17 and equation 18 establish many fundamental properties of the 2-collector transistor. Equation 17 establishes the maximum voltage drop within this cylindrical base region; this voltage is illustrated in Fig. 8 throughout a range of geometrical parameters associated with a typical 2-collector device. Further, equation 18 establishes the distribution of this base region voltage, thus showing the selective biasing which

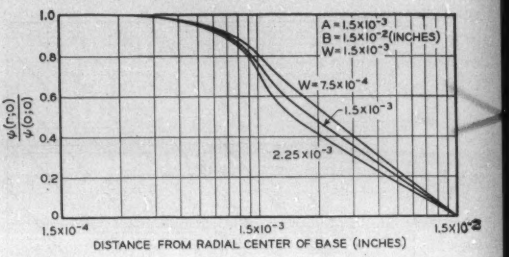

Fig. 10. Voltage distribution in base region (emitter side).

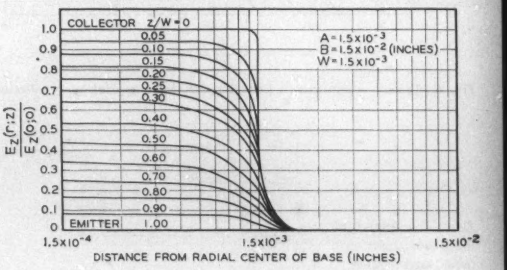

Fig. 11. Axial component of base region electric field.

is present at both the hook collector and emitter junctions; these distributions are illustrated in Figs. 9 and 10.

The axial and radial derivatives of the base region electrostatic potential (equation 16) constitute a minority carrier drift field which channels hole current from the emitter to the collector junction. From equation 16 we have

$$\text{(a)}\quad \frac{E_z(r;z)}{E_z(0;0)} = 2\,\frac{A}{B} \sum_{n=1}^{\infty} \frac{J_1\left(\alpha_n \frac{A}{B}\right) J_0\left(\alpha_n \frac{r}{B}\right)}{\alpha_n\, J_1^2\,(\alpha_n)} \frac{\sinh\left[\frac{\alpha_n}{B}(W-z)\right]}{\sinh\left(\alpha_n \frac{W}{B}\right)} \tag{19}$$

$$\text{(b)}\quad \frac{E_r(r;z)}{E_z(0;0)} = 2\,\frac{A}{B} \sum_{n=1}^{\infty} \frac{J_1\left(\alpha_n \frac{A}{B}\right) Jo\left(\alpha_n \frac{r}{B}\right)}{\alpha_n\, J_1^2\,(\alpha_n)} \frac{\cosh\left[\frac{\alpha_n}{B}(W-z)\right]}{\sinh\left(\alpha_n \frac{W}{B}\right)}$$

Illustrative examples of equation 19 are given in Fig. 11 and Fig. 12. An axially directed minority-carrier drift field exists immediately under the hook collector junction. Further, minority carriers outside the hook-collector radius are subject to a radially directed drift field which enhances their motion toward the center of this structure.

HOOK COLLECTOR INTERACTION

Hook collector interaction mechanisms enable one collector to maintain another in its low current mode of operation. This characteristic, attributable to a selective biasing of the emitter junction, is encountered throughout the entire operation cycle of a 2-collector device. Furthermore, this characteristic represents a

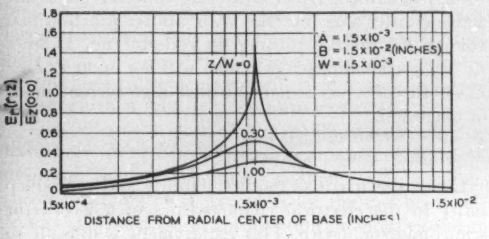

Fig. 12. Radial component of base region electric field.

principle of operation which is applicable to highly complex, multiple-collector logic devices; a single hook collector is capable of maintaining a large number of similar collectors in their low-current state of operation.

Inasmuch as we have used a 1-collector structure in the computation of base region electrostatic potential, it is convenient to retain this model (Fig. 13) during an investigation of hook collector interaction mechanisms. As previously shown, hook-collector current multiplication yields a radially distributed biasing potential $\psi(r;W)$ across the emitter junction face. This potential, in addition to the external bias V_{bc} is applied to the emitter circuit; the emitter junction bias $V_e(r)$ is thus given by

$$V_e(r) = \psi(r;W) + V_{bc} - V_{Re} \tag{20}$$

The parameter $\psi(r;W)$ can be analytically established from equation 17 and equation 18 at a specified magnitude of hook collector current. Furthermore, from classical p-n junction theory, the emitter bias $V_e(o)$ can be determined if we limit all minority carrier current to the emitter junction region opposite the col'ector. Substitution of these parameter, $\psi(0;W)$ and $V_e(o)$, into equation 20 yields

$$V_{Re} = \psi(0;W) + V_{bc} - V_e(0) \tag{21}$$

Therefore the radially distributed emitter junction voltage is approximated by

$$V_e(r) = -\{\psi(0;W) - \psi(r;W)\} - V_e(0) \tag{22}$$

Equation 22 establishes many important factors contributing to hook collector interaction. From Fig. 10 it is clearly seen that $\psi(o;W) \geqq \psi(r;W)$; therefore, when $|\psi(o;W)| > V_e(o)$, a portion of the emitter junction will be reverse biased. (This characteristic was suggested by S. Miller, IBM Research Division, Poughkeepsie, N.Y.) A properly designed multiple collector device will exhibit a forward biased emitter region comparable in size to the hook collector junction, thereby reducing minority carrier current to an adjacent collector.

Equations 19 establish another mechanism contributing to current commutation between two hook collectors. Assuming the active (forward biased) emitter area is restricted to a region immediately under the hook collector, the base region electric field, Fig. 13, channels all hole current from the emitter to the collector junction. An adjacent hook collector, therefore, can be exceedingly close to the active emitter area without receiving, through diffusion, a minority carrier current.

The exponential volt-ampere characteristic of an emitter junction maintains a desirable relation between the quantities characterized in equation 22. A small increase in emitter junction bias, $V_e(o)$, results in a large increase of base region electrostatic potential, and therefore a decrease of active emitter area. In a 2-collector device the active emitter region can be restricted to a very small area—often smaller than the hook collector junction—by properly adjusting the magnitude of hook electron current. If, on the other hand, an increase in emitter junction bias, $V_e(o)$, no longer increases the base region potential, the active emitter region becomes larger; through this mechanism an adjacent collector can be turned ON.

Saturation is exhibited by a hook collector, Fig. 2, when its current is essentially independent of emitter current and hence of emitter bias, $V_e(o)$. This saturation is caused by a removal of bias voltage from the hook collector junction due to resistive elements within the semiconductor device and its associated circuit. From Fig. 13, the collector junction bias, $V_c(r)$, is given by

$$V_c(r) = \psi(r;0) + V_{RL} - V_{bc} \tag{23}$$

where $\psi(r;o)$, the base region electrostatic potential, is obtained from equation 16. This collector voltage, $V_c(r)$, equation 23, is a radially distributed function with a minimum at $r=0$,

$$V_c(o) = \psi(0;0) + V_{RL} - V_{bc} \tag{24}$$

A sufficient magnitude of collector current, therefore, causes a zero bias at the center of each hook collector; this occurs when $|V_{RL}| = |V_{bc} - \psi(o;o)|$. Because the base region electrical resistance is much smaller than R_L, the collector current at which saturation occurs is principally determined by the load resistance, R_L, and the external collector bias V_{bc}.

The electrical characteristics of a 2-collector structure, Fig. 2, are a consequence of competition between each collector. At low magnitudes of emitter current, $0 < I_e < I_{e1}$, the two base region potential distributions are in competition for emitter hole current; a high-

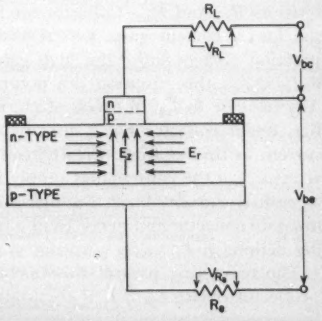

Fig. 13. A 1-collector semiconductor device.

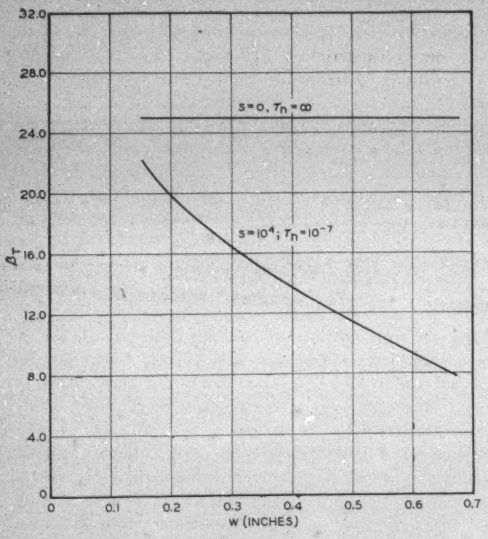

Fig. 14. Theoretical current gain of a cylindrical hook collector.

current mode of operation will be attained by the collector which introduces the largest base region potential and therefore has the largest current multiplication. Throughout this region of operation, an increase in emitter current I_e results in a decrease of active emitter area, thereby reducing minority carrier current to the hook collector of lowest multiplication.

Upon saturating the high-gain collector (no. 1), $I_{c1} = I_{c1}$, an increase of active emitter area is associated with an increase of bias voltage V_{be}. The additional emitter current, being rejected by one collector, contributes to base region recombination and to an increased current in the low-gain collector (no. 2). Collector current I_{c2}, when $I_{c1} < I_e < I_{c2}$, has been calculated by assuming the hole current is supplied from an emitter area comparable in size to the collector; bias upon this emitter region is approximated by the calculated magnitude of emitter voltage, $V_e(r)$, opposite the axial center of this hook collector.

Commutative switching between hook collectors ($I_e = I_{e2}$) is a result of properly selected collector load resistors R_{L1} and R_{L2}. Collector no. 2, assumed to have the lowest current gain, will reverse bias the emitter junction area opposite the high gain collector (no. 1) if $I_{c1} < I_{c2}$; this situation can occur when $R_{L1} > R_{L2}$. Any increase in I_{c2}, in excess of I_{c1}, reduces the emitter bias under collector no. 1, thereby decreasing emitter current at this location. Clearly, constant-current characteristics of the emitter bias supply result in a transfer of emitter current from the high-gain collector to the low-gain collector and hence yield a regenerative switching action.

The remaining part of this operating cycle for the 2-collector device $I_{c2} < I_e$ is essentially the same as previously described. Upon saturating collector no. 2, the active emitter area increases with emitter junction bias voltage V_{be} thereby turning ON collector no. 1. Since $I_{c1} < I_{c2}$—commutative switching will not occur at $I_e = I_{c3}$—both collectors remain in their high-current mode of operation.

EXPERIMENT

LOGIC APPLICATIONS require stability and reproducibility in the electrical characteristics of a 2-collector semiconductor device. This requirement is difficult to satisfy since the entire operating cycle is exceedingly dependent upon hook collector current multiplication; it is this parameter which must be controlled. Current multiplication, being equivalent to the common emitter current gain of a conventional junction transistor, is subject to variations due to changes in surface recombination velocity on the hook collector region. Such changes cannot be tolerated, since they introduce modifications in the illustrated electrical properties (Fig. 2). Specifically, I_{e1}, I_{e2}, I_{e3}, and also I_{c1} and I_{c2}, Fig. 2, must be design parameters which are not subject to appreciable change throughout the life of this semiconductor device.

Equation 3 suggests a method whereby a greater stability can be obtained in the current multiplication of a hook collector. A structure of specified gain β_T which also satisfies the inequality

$$\frac{1}{\beta_s} + \frac{1}{\beta_r} < \frac{1}{\beta_\gamma} \tag{25}$$

will be relatively insensitive to changes in minority carrier lifetime τ_n and surface recombination velocity s within the hook-collector region. Furthermore, the current multiplication of such a device is established by β_γ and, therefore, can be controlled through the diffusion characteristics introduced during construction. Fig 14 illustrates the calculated electrical characteristics of such a semiconductor device. This graph presents the theoretical current multiplication of a cylindrical hook collector with an ideal carrier transport efficiency in the

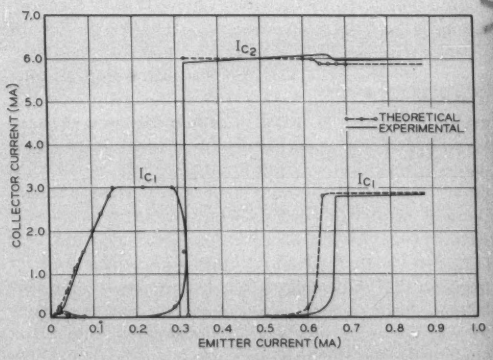

Fig. 15. Operation cycle of a 2-collector semiconductor device.

hook collector region ($\tau_n = \infty$; $s = 0$) and also with large surface and bulk recombination of minority carriers ($\tau_n = 10^{-7}$; $s = 10^4$). It is clearly seen that a suitably narrow hook collector region will yield a semiconductor device which is relatively insensitive to τ_n and s.

Two-collector devices, of the type illustrated in Fig. 1, have been constructed by the techniques of multiple diffusion, photolithographic masking, and etching, thereby forming mesa structures for the two hook collectors. This method of construction provides excellent control over the geometrical configuration, thus yielding devices closely approximating the idealized structures used throughout this analysis. Physical dimensions for these units were determined by the previously outlined analytical methods: $a = 0.0015$ inch; $B = 0.015$ inch; $C = 0.020$ inch; $w = 0.00015$ inch; $W = 0.0015$ inch.

The hook collectors were placed approximately 0.003 inch apart and symmetrically located about the center of a solid cylinder base region. Further, these devices were constructed from n-type germanium of 1 ohm-cm resistivity; the diffusion parameters C_{oa}, C_{od}, X_a, and X_d, were selected to yield a current multiplication β_γ of approximately 20.

In the diffusion of impurities into a semiconductor, adequate experimental control is not now available to obtain the required reproducibility of hook-collector current multiplication. Hook collectors, for example, taken from the same slice of semiconductor material exhibit a significant range in current gain—for example, 15 to 30—while a greater range is found when the hooks are from several slices within the same diffusion—possibly 10 to 40. Hook collectors obtained from different diffusions exhibit a sufficient range in current multiplication to suggest a complete lack of control over the diffusion parameters important to the electrical properties of a semiconductor device.

Interaction mechanisms are easily attained within this 2-collector structure; any unit having two good hook collectors would exhibit a commutation action of the type illustrated in Fig. 2. An analysis of the electrical characteristics for a two collector device, using measured values of current multiplication, show a satisfactory agreement between theory and experiment throughout the entire cycle of operation (Fig. 15).

CONCLUSIONS

HOOK COLLECTOR INTERACTION is a principle of operation which is applicable to the design of complex computer logic components. This interaction mechanism is well behaved; thus its characteristics can be adequately established by classical methods of analysis. Typical of such an approach to molecular electronics —where physical mechanisms are used to obtain unique electrical characteristics—a fundamental problem of reproducibility exists in the electrical properties of this semiconductor device. Before further steps are taken toward the application of collector interaction mechanisms, adequate control must first be obtained in the technology of impurity diffusion into a semiconductor material; this control should permit the reproducible construction of hook collectors to a specified magnitude of current multiplication.

NOMENCLATURE

A = Base region dimension (see Fig. 7)
B = Base region dimension (see Fig. 7)
B_τ = Minority carrier transport efficiency in hook collector region
C_o = Surface concentration of impurity atoms
D = Diffusion constant
E = Electric field
I_{pe}, I_{ne} = Total current (hole and electron) at hook emitter junction
I_{pc}, I_{nc} = Total current (hole and electron) at hook collector junction
I_c = Total hook collector current
I_e = Total emitter (large area) current
I_c^* = Total hook collector current when saturated
J = Flux density
L_a, L_d = Impurity diffusion parameter
L_n = Electron diffusion length
R = Resistance in external circuit (see Figs. 1, 13)
T = Temperature (Absolute)
V_{bc}, V_{bc} = External bias voltages (see Figs. 1, 13)
V_e, V_c = Bias voltages across emitter (large area) and collector junction
V_R, V_R = Voltages across R_L and R_e (see Fig. 13)
W = Base region width (see Fig. 7)

a = Hook collector radius (see Fig. 3)
k = Boltzman's constant
n = Electron density
q = Electron charge
r = Radial co-ordinate of solid cylinder
s = Surface recombination velocity
t = Time
w = Width of hook collector region (see Fig. 3)
z = Axial co-ordinate of solid cylinder

α = Alpha of hook collector
α_m = Root of equation 6(a)
α_n = Root of $J_o(x)$
β = Hook collector current multiplication
γ = Hook emitter minority carrier injection efficiency
μ = Mobility
τ = Minority carrier lifetime
ψ = Electrostatic potential

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Analysis of Switching Surges on a 220-Kv Line

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IN RECENT YEARS, improvements in lightning arrester characteristics have permitted reductions in transformer insulation levels and have led to extensive analysis and investigation of switching surges. Before the common use of reduced BIL transformers, switching surges were of no concern in most cases, since their magnitudes were well below the insulation strength of the windings. As transformer BIL is reduced, however, normal switching surges become a factor and arresters may be universally required for complete protection.

To provide adequate switching surge protection, both the arrester switching surge sparkover characteristics and the transformer switching surge insulation strength need be known. Both of these quantities will be a function of the shape and magnitude of the switching surge. The ability of the arresters to withstand the switching surge duty also depends on the magnitude and wave shape of the switching surge. Many miniature system studies have been performed in order to define these surge characteristics but field test data is meager.

To augment what little field test data is available, a series of switching surge tests were performed on the 75.5-mile 220-kv line which connects the Sunbury Station and the Siegfried Substation of the Pennsylvania Power & Light Company. Fig. 1 shows the single line equivalent of the test line and the pertinent terminal equipment.

Two methods of measurement were employed. Magnetic oscillographs recorded the three line currents, the three line-to-ground voltages and the breaker trip currents at Sunbury and Siegfried. Because of the limited high-frequency response of the magnetic oscillographs, cathode-ray oscilloscopes (CROs) and high-frequency response measuring techniques were employed to measure the three arrester currents and one line-to-ground voltage at Sunbury.

A total of 20 switching operations were performed during these tests. The 20 operations can be segregated in three separate test series as follows:

Test Series I—Energizing and De-energizing Open Line. With the transformer at Sunbury disconnected from the line, the breaker at Siegfried energized and de-energized the line. On two out of three line droppings breaker restrikes occurred and caused the arresters to operate. On two out of two line pick-up operations, the arresters also operated. In all four cases the measured arrester sparkover voltage was 1.4 times the crest rating of the arrester.

Test Series II—Energizing and De-energizing Line with Receiving End Transformers. The line was again switched from Siegfried but with the Sunbury transformer connected to the end of the line. No arrester operations occurred. The maximum arrester voltages recorded varied from 0.87 to 1.29 times the crest rating of the arrester.

Test Series III—Energizing and De-energizing Open Line Through a Transformer. With the Siegfried breaker the line was switched from the Sunbury end. Again no arrester operations occurred. Maximum arrester voltages were from 1.3 to 1.6 times the arrester rating.

The analysis of the arrester sparkover voltage data showed it to vary depending on the rate-of-rise of the switching surge voltage. In Test Series I, arrester sparkover occurred at 1.4 times the crest rating of the arrester but in Test Series III, arrester sparkover did not occur when the voltage rose to 1.6 times the arrester rating. In the first case the average rate of rise to arrester sparkover was about 600 to 900 volts per microsecond while in the latter case the average rate of rise was only 200 volts per microsecond. Both of these sparkover values are less than the 60-cycle sparkover rating of this arrester. This indicates the advisability of maintaining as high a 60-cycle sparkover rating as is compatible with good protection to equipment.

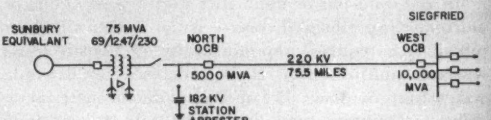

Fig. 1. Single line equivalent circuit of test line and pertinent terminal equipment.

Only one arrester current was successfully recorded but it is believed to be the first accurate oscillogram of a switching surge arrester current. The crest current magnitude was about 360 amperes and decreased to 50% of the crest value in 500 microseconds, and to 25% in 1,000 microseconds. Graphical methods of calculations were employed to estimate the wave shape and magnitude of the arrester currents which were not recorded by the CRO. These calculations showed crest currents of 130 and 220 amperes reducing to half value in about 700 and 200 microseconds for energizing and de-energizing the line, respectively.

The energy absorbed by the arrester for the case where both the arrester current and voltage were recorded was 60 kw-seconds. Calculations showed that this was approximately the total energy trapped on the line.

Digest of paper 61-44, "Field Tests of Lightning Arrester Voltage and Current Caused by Switching a 220-Kv Line," recommended by the AIEE Technical Operations Department for presentation at the AIEE Winter General Meeting, New York, N. Y., Jan. 29-Feb. 3, 1961. Published in AIEE Power Apparatus and Systems, June 1961, pp. 128-41.

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The Logic Potential of Molecular Electronics in the Multicollector Transistor

JOHN EARLE

In this article, means of using the phenomena of molecular electronics to perform logic are explored. Emphasis is on the 2-collector transistor, with occasional indications of the logical effects of more collectors.

IT IS in its infancy that we can most hope to influence an idea. Molecular electronics, lacking direction, can easily fall into the pattern of building the same circuits, only more compactly, in new technologies. Although this latter path may yield the most short-term gains, the integration of the logic approach with device development at IBM has shown the feasibility of switching in the solid state, of using the phenomena of molecular electronics in their own right to perform logic. This direction is not necessarily the easiest to take, but as side effects rather than as goals it should yield all the advantages of the other directions and, if successful, can be much more powerful.

SYNOPSIS AND CHARACTERISTICS*

AN EXPERIMENTAL INVESTIGATION by R. F. Rutz[1] of IBM in 1956 of the interaction of 2-hook collectors on a common substrate resulted in a new semiconductor switching device, the 2-collector transistor. Subsequent work by D. P. Kennedy[2] resulted in a workable design theory and fabrication techniques. An extension of the original geometry results in a device with multiple-hook collectors, interacting across a common junction. The multicollector device in one form is shown in Fig. 1. It consists of a series of p-n hook collectors on a large-area emitter-base junction. One of the interesting features of the device is the grounded-base transfer characteristic also shown in Fig. 1 for the simplest, 2-collector case. As can be seen from this curve, there are four possible steady-state conditions of the two collectors:†

State 1. Neither collector conducting (cut off)

State 2. Collector 1 conducting, and collector 2 not conducting

State 3. Collector 1 not conducting, and collector 2 conducting

State 4. Both collector 1 and collector 2 conducting (turned on)

The switching between (or among) collectors is controlled by the magnitude of the emitter current. A complex interaction of electric fields developed by the drops in the base region cause a focusing action at the emitter junction directly under the "on" collector. Starting in state 1 (see also Fig. 1), an increasing emitter current restricts the injection to a small area under the collector with the highest gain–bandwidth product (collector 1, *C1*), turning it on (state 2). Once driven into saturation, however, further increase in emitter current no longer flows directly to this collector and the excess minority carriers diffuse throughout the base region. Some of the carriers come under the influence of collector 2 (*C2*), starting to turn it on. Once *C2* is conducting, it acts as a negative resistance stealing current from *C1*. The load on *C2* is chosen to draw more current than *C1*, eventually forcing *C1* to cut off as *C2* saturates (state 3). Further increase in emitter current focuses a forward bias of the emitter-base junction under *C1* as well as *C2*, since the latter can absorb no more current. *C1* turns on and both collectors are in saturation (state 4 and Fig. 1).

Since the device is operated in the grounded-base mode and is essentially a p-n-p-n (or n-p-n-p) structure, it will (with proper circuit design) have both voltage and current gains, one of the requisites for the feedback circuits of this article. Furthermore, with the proper biasing, the device can drive several similar devices. An additional characteristic made use of in circuits described here is that when switching from *C1* to *C2*, *C2* will always turn on before *C1* turns off.

The previously published circuit by Rutz[1] has the

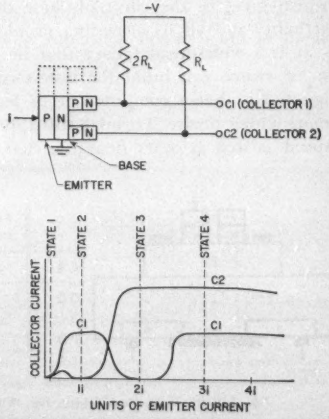

Fig. 1. Schematic diagram and characteristic curves for 2-collector transistor.

Essentially full text of conference paper CP60-878, presented at the AIEE Summer General Meeting, Atlantic City, N. J., June 19-24, 1960. Recommended for publication by the AIEE Solid State Devices Committee.

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*This synopsis was provided by P. R. Low.

†For four collectors, there would be 16 steady-state conditions.

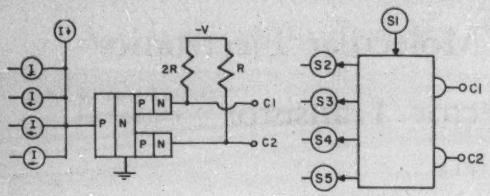


Fig. 2. (*Left*) schematic diagram and (*right*) block diagram of basic circuit device.

disadvantage that the input and output potentials are not compatible. This problem can be eliminated, however, by supplying a bias-current source at the emitter. The inputs would then be current sinks, subtracting from the total current available at the emitter. The circuit will then appear as in Fig. 2. One remaining problem, however, is that the digital voltage input to the circuit must be converted to analog current for the emitter. One method is to use a resistor network similar to that used in transistor–resistor logic. A better solution uses field-effect current limiters in place of the input, bias, and load resistors. This has the advantage that the current is almost independent of the input voltage once it has exceeded a given threshold. It is a small step from here to envision the field-effect current limiters fabricated as an inherent part of the emitter and collector regions, eliminating the need for nonsemiconductor components, as suggested by D. P. Kennedy. Such an integrated device might appear as Fig. 3.

A number of 2-collector circuits have been designed and tested. Switching times of a few hundred nanoseconds have been observed even with these experimental devices.

LOGIC DEVICES

THESE DAYS, when our switching circuits are fighting the speed of light in their wired connections and other laws of nature in packaging density, power dissipation, greater complexity with higher reliability, and so on, one may find refreshment in considering an approach which gives us the effect of these things without the actuality and all its attending problems.

It is a widespread fallacy that he with the highest-speed switch can build the fastest computer. What is ignored is that a computer needs less a "switch" and more a logic device. Through this approach, the effect of speed as well as other desirable characteristics may be gained, and computer technology may take one of its infrequent basic steps forward.

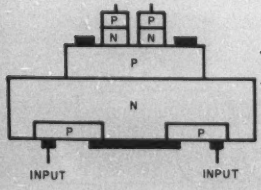
The basic logic building blocks in today's digital systems have one characteristic in common that singles them out from the infinity of possible, functionally complete building blocks. They are characterized by having exactly one "1" or one "0" in their function tables, regardless of the number of variables for which they are defined. Fig. 4 illustrates this in two variables for the most common ones. This results in a nearly unique synthesis of larger functions using these blocks. That is, the canonical form of the synthesized functions is unique within the sense of duality. Thus, minimalization in second-order equation form may be approximated with standard techniques. This is true for other than AND and OR functions satisfying this condition, provided we supplement the procedure with some additional rules dependent on the functions used, although this is not generally realized.* Treatment of this problem for two important functions can be found in reference 3 and circuits implementing them in reference 4. Synthesis within any sense of minimality has not been solved for functions with multiple ones and zeros in their tables. In some cases synthesis at all is difficult. A simple example of a multiple "1" function of current interest is the majority function used particularly in microwave switching.

One of the most powerful aspects of devices which perform multiple "1" functions is that they cannot tell one "1" from another. That is, if the device is compatible with itself circuitwise and has gain greater than unity, it has possibilities of bistability with d-c stability in its different "1" states. (This will be shown later.) One such device is considered in this article and its stability potential is exhaustively explored. Although independently developed, there is paper in the literature that treats these multiple "1" functions, and although much of this paper uses the same 2-collector transistor for illustration, neither the approaches nor results overlap but are complementary.[5]

COMBINATORIAL POWER OF A SINGLE 2-COLLECTOR TRANSISTOR

THE SIMPLEST multicollector transistor that still retains the crucial switching action among hook collectors, is the 2-collector version. We shall largely con-

*This addition of a few simple rules is adequate only if the basic set of functions is functionally complete and contains either no redundant functions or no more than one function which is the dual of another in the set.



	FUNCTIONS EQUAL TO ONE FOR A UNIQUE ROW			FUNCTIONS EQUAL TO ZERO FOR A UNIQUE ROW			A FUNCTION WITH A UNIQUE ROW FOR BOTH ONE AND ZERO
AB	A·B	$\bar{A}\,\bar{B}$	$A\,\bar{B}$	A+B	$\bar{A}+\bar{B}$	$A+\bar{B}$	$\bar{B}$
00	0	1	0	0	1	1	1
01	0	0	0	1	1	0	0
10	0	0	1	1	1	1	
11	1	0	0	1	0	1	

Fig. 3 (*left*). Integrated device. Fig. 4 (*right*). Tables for common functions having output for one row uniquely one or zero.

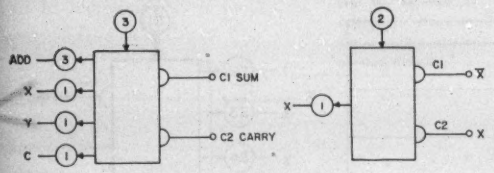


Fig. 5 (*left*). Single-element full adder circuit device. Fig. 6 (*right*). Inverting and noninverting amplifier with negligible skew between outputs.

fine ourselves to this case with occasional indications of the logical effects of more collectors.

The most negative potential of an input or a collector will be referred to as "0" (logical zero); the most positive as "1" (logical one). The logic block symbol for the device is shown in Fig. 2. The circles will contain the number of current units supplied by *S1*, and drawn by *S2* through *S5* when the latter inputs are at "0." One unit of emitter current is defined as that current which will reliably hold *C1* in saturation and *C2* cut off.

The most obvious usage of this device is suggested in the collector–emitter plot of Fig. 1. Collector 1 saturates for one and three units of emitter current. If each current unit were generated by the presence of an input voltage variable in the logical "1" state, *C1* would give the sum modulo two, or binary sum, of the three variables. Collector 2 saturates for two and three units of emitter current. This is the carry expression of binary addition. Thus, a single device can be used as a full adder. The block diagram of Fig. 5 shows the configuration. This single, solid-state device is directly performing two different logical functions which, for example, in the NOR circuit[3,4] would require about nine transistors and possibly a delay of six levels of gating.

The Add line is a control which when at "0" takes all the current, allowing no emitter current and holding both collectors off. If Add is up, however, and exactly one of the inputs *x*, *y*, or carry *c* is up, the other two will drain two units of currents, leaving one unit of emitter current saturating *C1* and holding *C2* cut off. The sum is "1" and the carry is "0." If any two of the inputs are up, there is a 1-unit current drain, and the remaining two units saturate *C2* and hold *C1* cut off. The sum is "0" and the carry is "1." If all three are up, there are three units of emitter current and both collectors saturate; the sum and carry are both "1." This circuit without the Add control and some of its combinatorial potential for functions of two variables has been published elsewhere.[1,5]

This circuit element has many useful modes as a 2-output device. For example, it can operate as both an inverting and a noninverting amplifier at the same time, with very little skew between the two signals (as shown in Fig. 6). The physics of the device in this configuration requires, for example, that to turn on *C2* the device must turn off *C1*. Thus the signals are not a block of delay apart, as usually happens. This inversion is significant in that the device is basically a noninverting circuit (a grounded base driving a grounded collector).

In other configurations the 2-collector transistor can operate as both an amplifier and a logic block at the same time. In Fig. 7, for example,

$$C1 = xy + xz$$

$$C2 = x$$

Collector 1 is performing logic with the inputs, while collector 2 is amplifying one of them. This block increases the branch-out factor of the *x* variable rather than decreasing it, as most loading does. In this case, instead, by driving a load such as Fig. 7, we have the effect of increasing the number of loads that can be driven.

Another increased loading circuit is shown in Fig. 8, where

$$C1 = txyz$$

$$C2 = txyz$$

The loading capabilities of the collectors are independent, so this 4-input AND can drive twice the single-collector capacity. Notice also that the increased drive is not at the expense of speed as in conventional circuitry.

The two outputs can perform logic independently as well. A simple example is Fig. 9, item *a*, where

$$C1 = xy\bar{z}$$

$$C2 = xyz$$

This could save the need for an inverter and the delay it entails if both functions were required.

The circuit of Fig. 9, item *b*, in addition to being a useful 2-output block of three variables, shows one of the interesting possibilities of this transistor in clocked systems. If *z* were a clock or control signal, we would have an AND and an OR output gated with the clock pulse.

$$C1 = z \cdot (x + y)$$

$$C2 = z \cdot (x \cdot y)$$

In an interesting hybrid of this (Fig. 9, item *c*) we get the same two variable functions, but only one of them is clocked.

$$C1 = z \cdot (x + y)$$

$$C2 = x \cdot y$$

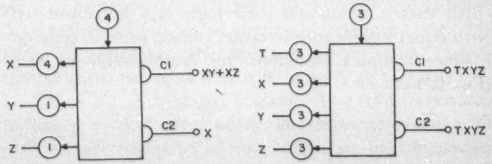
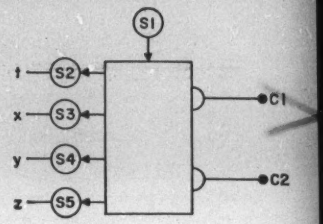


Fig. 7 (*left*). Circuit acting simultaneously as a logic block and an amplifier. Fig. 8 (*right*). Logic block with double the normal drive. Doubling drive here does not delay signal.

	t	x	y	z	
	S1	S2	S3	S4	S5	
a	2	0	2	2	1	C1 = $xy\bar{z}$ C2 = xyz
b	4	0	3	3	4	C1 = z·(x+y) C2 = z·(x·y)
c	3	0	2	2	1	C1 = z·(x+y) C2 = x·y
d	4	0	4	3	1	C1 = x·(y+z) C2 = x·y
e	3	1	1	1	1	C1 = $tx\bar{y}\bar{z} + \bar{t}x\bar{y}z + t\bar{x}\bar{y}z + \bar{t}\bar{x}yz + txyz + \bar{t}xy\bar{z} + t\bar{x}y\bar{z}$ C2 = txz + txy + xyz + tyz
	3	1	1	1	2	C1 = $txy + \bar{t}\bar{x}yz + \bar{t}x\bar{y}z + t\bar{x}\bar{y}z$ C2 = txz + xyz + tyz
	3	1	1	2	2	C1 = $txz + txy + \bar{t}\bar{x}yz$ C2 = xyz + tyz
	3	1	2	2	2	C1 = txy + txz + tyz C2 = xyz
	3	2	2	2	2	C1 = tyz + xyz + txy + txz C2 = txyz
	3	1	1	1	3	C1 = $\bar{t}\bar{x}yz + txyz + t\bar{x}\bar{y}z + \bar{t}x\bar{y}z$ (full adder with z on C2 = xyz + tyz + txz add control signal)
	3	1	1	2	3	C1 = txz + $\bar{t}\bar{x}yz$ C2 = tyz + xyz
	3	1	2	2	3	C1 = tyz + txz C2 = xyz
	3	2	2	2	3	C1 = txz + tyz + xyz C2 = txyz
	3	1	1	3	3	C1 = $\bar{t}\bar{x}yz + txyz$ C2 = tyz + xyz
	3	1	2	3	3	C1 = tyz C2 = xyz
	3	2	2	3	3	C1 = tyz + xyz C2 = txyz
	3	1	3	3	3	C1 = txyz C2 = xyz
	3	2	3	3	3	C1 = xyz C2 = txyz
	3	3	3	3	3	C1 = txyz C2 = txyz



Each current sink S_i may take values 1, 2, 3, or 4. If $S1 = 3$ and $S3 = 2$, for example, it means that when x is logical zero, then and only then will $S3$ drain two units of current from the 3-unit source, if available. No more than $S1$ units can drain at one time. An $Si = 0$ means it is not in the circuit. One unit of current is defined as that amount of emitter current necessary to saturate $C1$ and hold $C2$ cut off.

Fig. 9. Logical functions that may be synthesized by using the current-sink values in the left columns.

Another possibility is to clock or gate an amplifier output as well as a logic output. Assume x is a clock signal (Fig. 9, item *d*).

$$C1 = x \cdot (y + z)$$
$$C2 = x \cdot (y)$$

One output is a function of all three input variables, the other of only two.

All these circuits and their logic may be considered with equal significance in either pulsed or level systems.

More complex functions are synthesizable as well (Fig. 9, item *e*):

$$C1 = t\bar{x}\bar{y}\bar{z} + \bar{t}x\bar{y}z + t\bar{x}\bar{y}z + \bar{t}\bar{x}yz + txyz + \bar{t}xy\bar{z} + t\bar{x}y\bar{z}$$
$$C2 = txz + txy + xyz + tyz$$

(Incidentally, these equations are all given in algebraic minimal form.) Using the NOR circuit,[3,4] to synthesize these two functions in two levels (to keep close to the number of delay—one—in the 2-collector circuit) would require more than a dozen transistors, depending on the number of inputs allowable, plus four more transistors for input inverters to $C1$ if complements were not available. Further, in the two functions all four signals (not including any inverters driven) must drive seven gates. In the 2-collector circuit, each variable drives but one load, and inversion and its delay are unnecessary. The 2-collector transistor's potential as a 2-output device lies largely in the fact that a given function is usually realizable in several different configurations, each with a different function at the other collector. Thus one has a fair chance of selecting a circuit where the second output is usable.

Besides these examples, there are a great many more functions of three and four variables capable of being generated with a single element. A few of these are listed in Fig. 9 along with the circuit parameters for

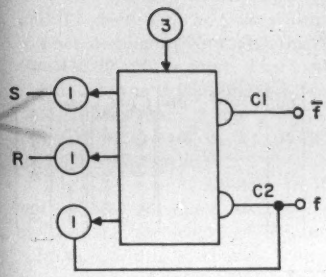


Fig. 10. Set-reset 2-collector transistor circuit with complemented outputs.

their generation. Some measure of their number may be given by a comparison with the number of classes of functions of three variables. Each class contains all the functions of three variables equivalent under inversions and permutations of the variables. There are 20 such classes.[6]

The 2-collector transistor can synthesize a number of functions within each class of all but three classes. In addition, it can synthesize a large number of 4-variable functions. The combinatorial logic potential increases with the number of collectors, providing the number of inputs and the permissible range of their current-sink values keep pace.

By way of comparison a study was made of the number of transistor NOR circuits[3,4] necessary to synthesize this same set of classes of functions. It was found to average 3.1 transistors per class as opposed to the one 2-collector transistor per class.

What takes two to six or more levels of gating in the NOR and most transistor circuits requires only one level in the 2-collector transistor. Thus, assuming equal switching speeds of both circuits, the effective speed of the 2-collector circuit is at least doubled and, since the number of blocks is fewer, the number of mechanical connections is reduced. And whenever the outputs of both collectors can be used, we have even greater savings.

SINGLE-ELEMENT SEQUENTIAL CIRCUITS

THE 2-COLLECTOR TRANSISTOR is perhaps even more potent as a bistable device. The simplest bistable configuration is shown in Fig. 10. Here, its multiple-one nature allows us to use it as a d-c set-reset flip-flop.

Starting in the zero state, $\overline{f}$ is one and f is zero. S is normally down and R is normally up. S and f each draw one unit of current, leaving one unit of emitter current which holds $\overline{f}$ on and f off. The system is stable.

When we bring S up, another unit of current goes to the emitter; this $2i$ starts to bring $C2$ up and $C1$ down, but $C2$ going up switches in all three units of emitter current, holding both $C1$ and $C2$ at "1." In this transition to the "1" state, both f and $\overline{f}$ are "1." This condition is stable as long as S remains up. When S returns to zero, one unit of current is drained. However, R and f are now up, so the emitter receives $2i$, $\overline{f}$ goes to zero, and f stays "1." The system is now stable in the "1" state. In the transition to the "1" state, stability with d-c inputs was allowed by the multiple-one aspect of $C2$. That is, collector 2 was a "1" both when S went up (for $3i$, state 4) and after S went down (for $2i$, state 3; see Fig. 1).

If we now bring R down, a current of $2i$ is being drained through R and S. The $1i$ resultant emitter current turns $C2$ off and its feedback loop drains the last unit of current, bringing $C1$ down to zero. In this transition to the zero state, both f and $\overline{f}$ are held stable at zero.

When R returns to one, S and f drain two units of current and the remaining $1i$ brings $\overline{f}$ to one and holds f at zero. The system has returned to the zero state. Note that applying simultaneous pulses to the set and reset does not affect the flip-flop, since the $1i$ drain to the reset is supplied by the set.

This is by no means the only flip-flop that can be built. In fact, there are a very large number of logically different flip-flops that can be synthesized with the single device. These can be broken into two classes: one requires pulse-width control of the inputs similar to that of an Eccles-Jordan binary trigger; the other operates d-c, largely independent of the input rise times. There are a large number of very interesting such flip-flops, all more interesting than the Eccles-Jordan from the logical point of view. A few of the a-c flip-flops are shown in Fig. 11.

Fig. 12 shows a typical a-c flip-flop. The two inputs to this device, $T1$ and $T2$, will separately trigger the $C1$ collector, provided their pulse width is just less than the oscillation period of the device. When pulsed simultaneously, they set the device to a "1" state. The two inputs are normally "1." The triggering pulses bring them to zero. Suitable pulse-width control, such as a positively clamped differentiating network, must exist at the inputs.

In order that the operation of this device may be discerned, some care must be taken in a stability analysis. The excitation matrix of Fig. 12 shows the states of the feedback loops along the rows and the states of the input variables along the columns. At the intersection of each column and row is the output which the circuit will try to achieve under those input conditions. If the excitation on the feedback loops and the outputs are the same for fixed inputs, the device is stable. This is indicated in the transition matrix by circles in the stable boxes. The dots in the boxes correspond to unstable conditions, when the output the circuit is trying to achieve differs from the present output.

The device does not always go where it is trying to go. For example: $C1 = 1$, $C2 = 0$, $T1 = T2 = 1$; here both collectors will try to change, $C1$ to go off and $C2$ to go on. However, the device turns on much faster than it turns off, so that it will actually go to $C1 = C2 = T1 = T2 = 1$, which is stable. The transitions are indicated by the arrows in the transition matrix.

There are two pairs of nonstable states which, when entered, will cause the device to oscillate as shown by the arrows. Suppose we start in state 1, the zero state. $T1$ and $T2$ are normally one, $C1$ is zero, and $C2$ is one.

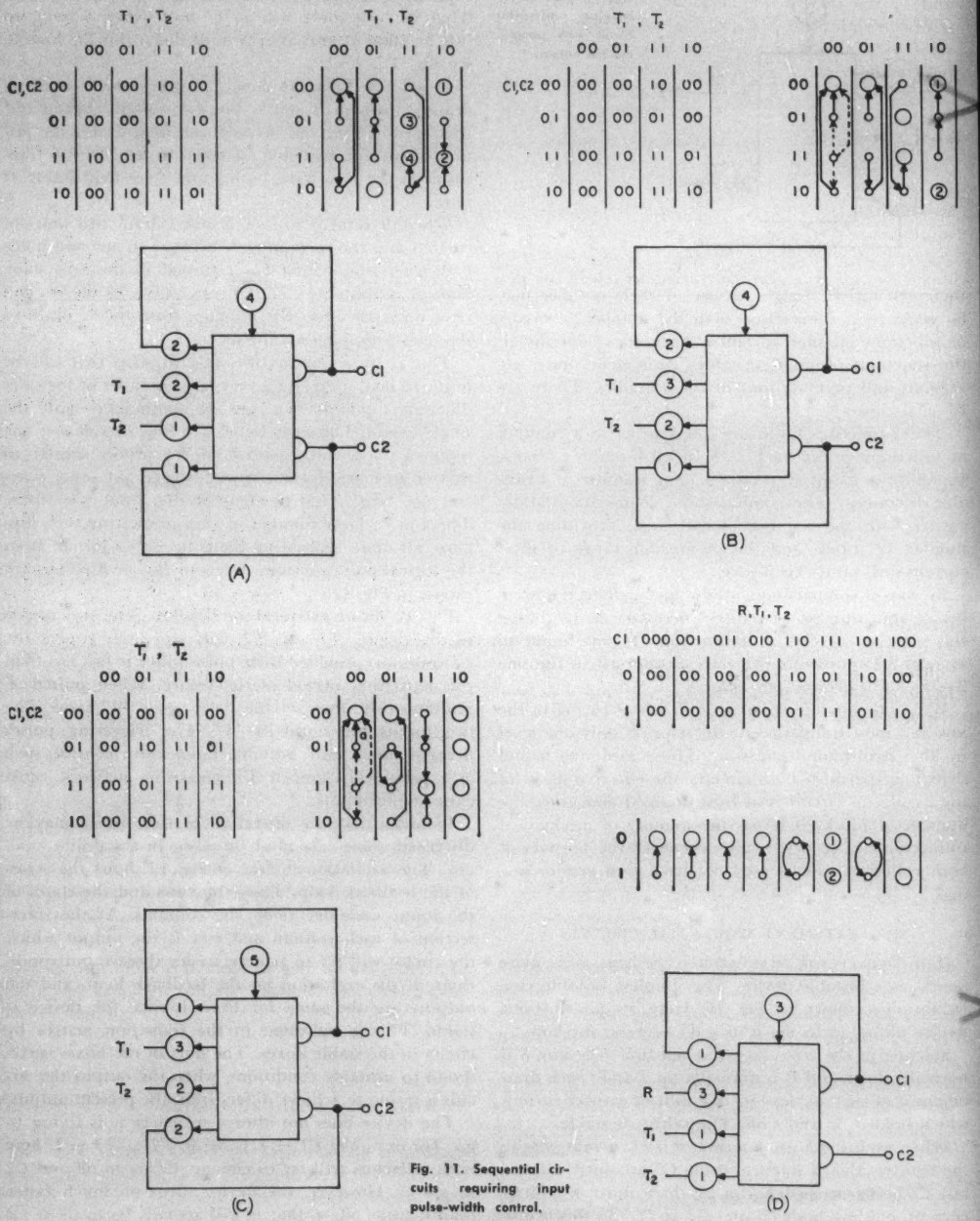


Fig. 11. Sequential circuits requiring input pulse-width control.

If *T1* is brought down to zero and held there just long enough to change rows in the matrix, the device will settle in stable state 2 with $C2 = 1$. A similar transition to state 1 will occur going through the same pulse sequence. Clearly, identical circuit action may be accomplished by pulsing *T2* in the same fashion. A similar analysis shows the device will set if both inputs are pulsed simultaneously.

As another example, consider the circuit of Fig. 9 (A). Here we can normally sit in stable states 1 or 2. *T2* sets

and *T1* resets with no pulse-width control. The device is reset dominant. Note also that both outputs in the stable state are the same. This means that this flip-flop has double the drive potential.

If we used states 3 and 4 as "home," and *T1* were pulse-width controlled, *T1* would trigger the device and *T2* would set it.

The other class of flip-flops are d-c, largely independent of input rise times, such as Fig. 10, having no restriction on the length of the input pulses (except a minimum width, of course). These are all more interesting, and more powerful, than the typical set-reset flip-flop of the Eccles-Jordan variety. A few of the possible ones are shown in Fig. 13.

The circuit of Fig. 13 (A), for example, has two reset inputs and one set input. If *S* only is pulsed, the device sets. For any other combination of inputs except the normal home column, the device resets.

Again these are but examples. A large number of the possible bistable 3-input flip-flops can be synthesized. One must not make the mistake, however, of seeing these flip-flops as merely differing in a nearly trivial way with respect to current-sink values. Their logical difference is enormous. In effect, these are flip-flops with two levels of gating in the set and reset lines. Fig. 14 compares a typical 2-collector flip-flop with its logical equivalent laid out in NOR circuitry. Not only do we have (in this example) a 6-to-1 ratio of components, but also a 2- or 3-to-1 ratio in delays, assuming equivalent delays per block. Note also that the 2-collector transistor loads down the signals much less than the other.

MULTIELEMENT SEQUENTIAL CIRCUITS

THE 2-COLLECTOR transistor circuits combine to handle larger sequential problems as efficiently as they handled 2-stable-state problems. A shift register takes two elements per bit (see Fig. 15). Here it is of interest to note again a property of this device which is a great saving in sequential circuits. The 2-collector transistor turns on faster than it turns off, and it appears that it can be made reliably so. We see a usage of it in this circuit.

A flow table of the circuit is shown below each stage of the shift register. *A* is the flip-flop normally holding the information, and *B* acts as a transfer stage during shifting. With Shift equal to zero and Not Shift equal to one, *A* and *B* are stable; *B* equals zero and *A* equals one or zero. I_1 is, like I_3, equal to zero.

Assume *A* is in stable state 5, the "1" state; *B* in stable state 4, *C* in state 1. As Shift goes to one, Not Shift to zero, device *B* turns on before *A* turns off (device specification). *B* goes to stable state (2), *A* goes to 4 or 6 depending on input, sending *B* to state 5 and *C* to 4.

When Not Shift goes to one and Shift to zero, the same sequence (by symmetry) transfers *B* to *A*. So each information state gets reset each Shift or Not Shift pulse, but before it gets reset and providing it was in a "1" state, the next stage gets set. Note that in the normal stable states 1 and 5 the complemented outputs are available. The same circuit can be used as a ring using only one element per bit.

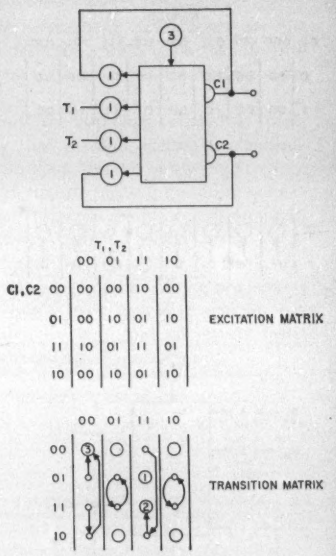


Fig. 12. A 2-input binary trigger circuit where pulsing both inputs sets the feedback to 1. Pulse-width control of inputs is necessary.

Fig. 16 shows a d-c binary trigger whose operation is largely independent of the input rise time. Assume *C1* as the zero state of the trigger and *C2* as the one state. Starting from the zero state, conditions are: *C1*, *C2*, and *T* are at zero. $\overline{T}$ and *C1* are at one. There is no emitter current in device *B* and both collectors remain off. There is one unit of emitter current in device *A* holding *C1* on due to the 2-unit drain, one to *C1* and one to *C2*. This is stable.

When *T* goes to one there is a two unit drain from device *B* to *C2'*; the remaining unit of current turns *C1'* on. Meanwhile $\overline{T}$ goes to zero and *C1* follows. This is a transitional stable state.

When $\overline{T}$ returns to one there is a transient one unit of current drain to *C2* leaving two units to turn on *C2*. *C1'* follows *T* down to zero and provides the 1-unit drain necessary to hold *C2* on. We are now in the stable "1" state. This transition is possible because *A* turns on faster than *B* turns off.

When *T* goes to one again, *C2'* goes up and *C2* goes down, resulting in a transition stable state. *T* going down turns *C1* on and *C2'* off and we are back to the zero state.

Bench testing has verified the basic assumptions about device response and confirmed predictions of sequential circuit operations in what often involved highly complex sequences of interactions among collectors, inputs, and feedback loops.

CONCLUSION

THE EFFECT of this device is to compress more of the switching into a single device by controlling the carriers across interacting junctions. This tends to increase

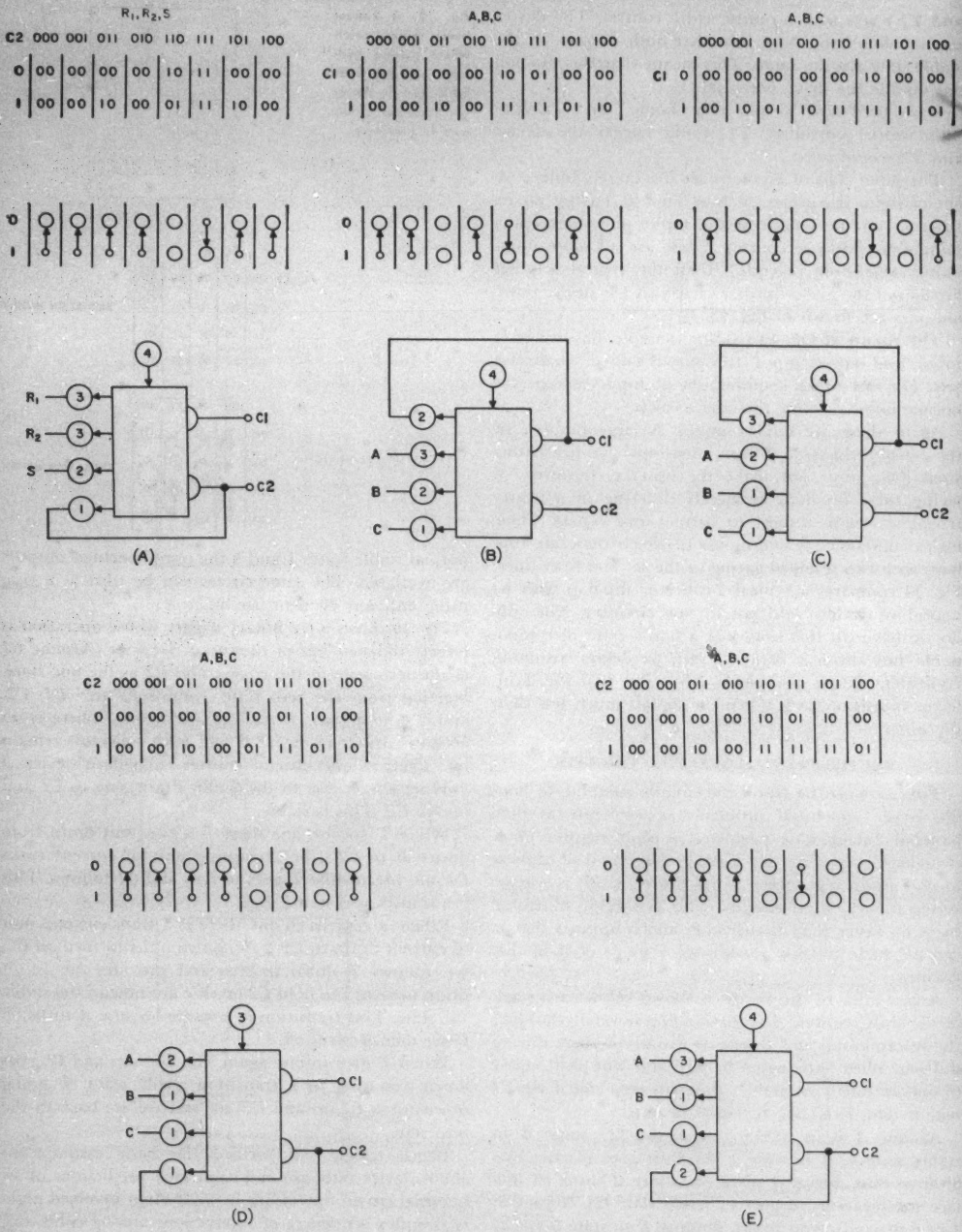


Fig. 13. D-c sequential circuits the operation of which is largely independent of input rise time.

effective switching speeds and decrease component count and mechanical connections. It can also have the effect of greater driving power and packaging density.

In some combinatorial circuits the logical design becomes greatly simplified. There is no need to minimize a function of three variables; it can be done in

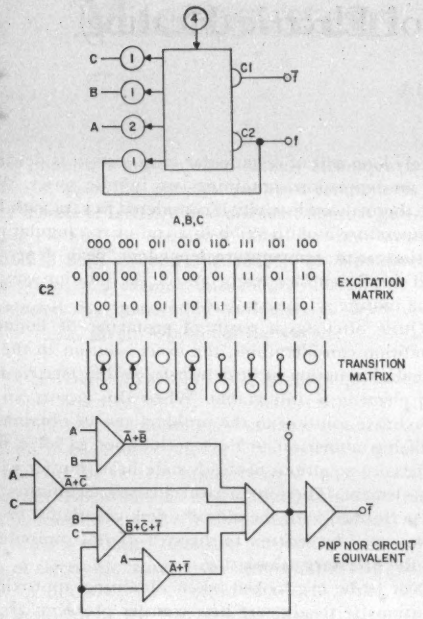


Fig. 14. Comparison of component count and levels of delay of a typical 2-collector sequential circuit (top) and its NOR equivalent (bottom).

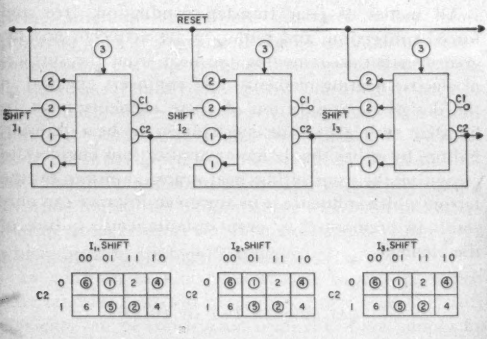


Fig. 15. Two element per bit shift register (or one element per bit ring counter).

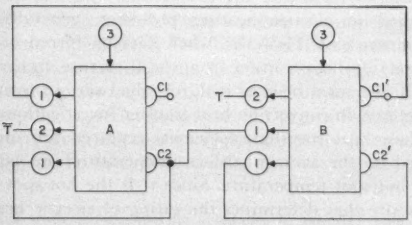


Fig. 16. D-c binary trigger.

a single device. The selection of the circuit for the function is efficiently handled with a table look-up procedure which makes it very amenable to computer design of computers.

In sequential circuits the flip-flops contain so much combinatorial power that in some cases the combinatorial circuitry is eliminated. Instead of having flip-flops feeding combinatorial circuits feeding flip-flops, we can have flip-flops feeding flip-flops with no loss in logic. An example is the shift register in Fig. 15.

In conclusion, it should be pointed out that this article indicates not merely usage of this device nor merely of this phenomena; but a basic new direction for our research, one in which we may find effectively faster speeds and fewer components.

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Redstone A-7 Rocket Engine

A rocket engine identical to one that launched the first U. S. astronaut into space is readied for shipment from Rocketdyne, a division of North American Aviation, Inc. The liquid propellant A-7 burns alcohol and liquid oxygen. "Workhorse" engine has set unprecedented reliability record in 71 previous launchings.

Heat Transfer Aspects of Electric Heating

B. ROLSMA

JOULEAN HEAT generated when an electric current passes through a conductor is considered to be an undesirable by-product by the majority of electrical engineers engaged in designing electric apparatus and, therefore, great care is taken to reduce it to a minimum in these designs. Electric heating element designers, on the other hand, are continually searching for new ways to generate more heat. In one respect, however, both the designer of electric apparatus and the designer of electric heating elements have a common goal in that both are desirous of dissipating the generated heat with as small a temperature differential as possible between the hottest point within their respective equipments and ambient.

Although not physically separable, the heat transfer aspects of electric heating, for discussion purposes, are divided into two general areas: heat transfer within the elements, and heat transfer from the surfaces of elements. It is well recognized that the temperature within an electric heating element is determined to a large degree by the rate of heat transfer from the surface of the element; however, the engineer applying stock heaters is not interested in the internal heat transfer problem, but in the problem of dissipating the energy from the surface of the element; hence, the division between the internal and external problems.

Since the basic differential equations describing the steady-state heat transfer with Joulean heat generation for electric windings, or coils, are identical to those which may be written for electric heating elements, the solutions obtained for the temperature distribution within electric coils are directly applicable to the design of electric heating elements provided, of course, that the geometric and boundary conditions correspond. Exact solutions to the differential equations for steady-state heat transfer within electric coils with heat generation are available in the technical literature, and these range in form from quite simple algebraic equations to very complex relationships involving several infinite series expressions. The least complex solutions apply to coils or heating elements having the shapes of an infinitely wide plate, an infinitely long cylinder, or a sphere, considering that the surface temperature of the coil is fixed and that the thermal conductivity of the coil material and the rate of heat generation are invariant with temperature throughout the coil. Although the boundary conditions and assumptions are unchanged from those just cited, the temperature within an infinitely long coil of rectangular cross section is described by an expression containing two infinite series. When the thermal conductivity is considered to vary with both temperature and direction in a coil of rectangular cross section with temperature-dependent heat generation and varying surface temperatures, the solution contains four infinite series expressions.

Quite often, as a result of geometric or boundary condition considerations, the exact solution to the differential equation of heat transfer within electric heating element is intractable. When this occurs an approximate solution to the problem can be obtained by utilizing numerical analysis techniques to solve finite difference equations of steady-state heat transfer within the element. These numerical analysis techniques may be performed with the aid of a desk calculator, or programs may be written to direct a digital computer to do the necessary calculating.

Not to be overlooked when obtaining approximate solutions to steady-state heat transfer problems are the simulation or analog techniques. When, as is considered here, steady-state conditions exist, the passive- or network-type analog computer is generally more suitable than the active or electronic computer.

All modes of heat transfer, conduction, free and forced convection, and radiation are active to one degree or other in removing the heat from the surfaces of electric heating elements, and engineers engaged in the design or application of these elements must be familiar with all of the mechanisms of heat transfer. Failure by either the design or applications engineer to recognize the controlling heat transfer means or the factors which influence it in any given instance can only result in premature, or even instantaneous, failure of the element.

CAUTION IN USE OF DATA

MUCH INFORMATION in the literature on heat transfer from surfaces can be directly applied to electric heating element design and application. When data on heat transfer by radiation and conduction from surfaces are applied to electric heating problems, generally, no problems arise. However, when data on forced or free convection heat transfer from the literature are considered, care must be exercised, for when surface temperatures vary in convection heat transfer investigations, the surface heat transfer coefficients reported are usually based on the average surface temperature and not on the hot spot temperature. Since it is the hot spot temperature that determines the rating of electric heating elements, surface coefficients based on average surface temperatures are not applicable.

Digest of paper 61-30, recommended by the AIEE Electric Heating Committee and approved by the AIEE Technical Operations Department for presentation at the AIEE Winter General Meeting, New York, N. Y., Jan. 29–Feb. 3, 1961. Published in AIEE *Applications and Industry*, May 1961, pp. 28-33.

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Microsystem Circuit Analysis

P. S. CASTRO

An important microminiaturization technique is that of realizing complex network components by means of resistive and dielectric films. A general method for analyzing these film-type networks, built around the theory of indefinite matrices, is presented and simple rules are developed for generating subnetworks from a given 4-terminal network.

CONSIDERABLE EFFORT has been expended in the investigation of the characteristics of thin films and the application of these films as circuit elements in electrical circuits.[1-5] The motivation behind this effort is the current intensive need for microminiaturization. Essentially of zero volume, thin films make the inherent density of circuit elements produced from such films very high. Complete circuits constructed of films of electronic materials are included in the generic name of microsystems electronics, which is the official term adopted by the AIEE Solid State Devices Committee.

The reduction of volume afforded by microminiaturization techniques is now recognized by many as not being the primary goal of such techniques.[6] In fact, extreme microminiaturization generally raises more problems than it solves with regard to handling, interconnections, etc. One of the primary goals of microminiaturization is increased reliability. The microsystem electronics technologies increase reliability through a reduction in the number of connections which must be hand soldered. Interconnections between films are made during fabrication and form an integral part of the circuit. By using highly stable film materials and film protective coatings, film resistors and capacitors can be constructed which, in turn, are highly stable.

In addition to film resistors and capacitors, which have familiar electrical properties, a new class of circuit elements can be constructed from thin films simply by depositing resistive and dielectric films so that their electromagnetic fields interact.[2-4,7] These circuit elements are called distributed parameter networks and have interesting and novel circuit functions which cannot be realized using a finite number of lumped resistances and capacitances. Four basic distributed parameter networks are considered. Two of these can be realized using existing materials and techniques; the other two require material properties not presently available, but their electrical characteristics are easily inferred by analogy to the first two networks.

A special article recommended for publication by the AIEE Solid State Devices Committee.

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THE R-C-NR NETWORK

CONSIDER the basic structure shown in Fig. 1(a). This structure consists of a dielectric film sandwiched by two resistive films and is referred to as an *R-C-NR* network.[7] By a combination of several such structures, more complex configurations can be realized. Alternatively, by selecting appropriate values of N and suitably selecting interconnections between the four terminals of this basic structure, a complete series of subnetworks may be obtained.

Analysis of the R-C-NR Network. The equivalent circuit of an elemental section of the basic structure, Fig. 1(b), gives the differential equations governing the sinusoidal steady-state voltages and currents as

$$\frac{d^2v}{dx^2} = j\omega\,(1 + N)rcv \tag{1}$$

and

$$\frac{di_1}{dx} = -\frac{di_2}{dx} = -j\omega cv \tag{2}$$

where ω is the angular frequency of the impressed sinusoid, and r and c (assumed constant) are the resistances and capacitances, respectively, of the films per unit length and per unit width. This analysis neglects edge effects of the films. It should be noted that these equations are diffusion equations.

The solutions to these equations are

$$v = A\epsilon^{\alpha x} + B\epsilon^{-\alpha x} \tag{3}$$

$$i_1 = -\frac{j\omega c}{\alpha}\,(A\epsilon^{\alpha x} - B\epsilon^{-\alpha x}) + D_1 \tag{4}$$

and

$$i_2 = \frac{j\omega c}{\alpha}\,(A\epsilon^{\alpha x} - B\epsilon^{-\alpha x}) + D_2 \tag{5}$$

where A, B, D_1, and D_2 are arbitrary constants and

$$\alpha = \sqrt{j\omega(1 + N)rc} \tag{6}$$

Evaluating these arbitrary constants in terms of voltages

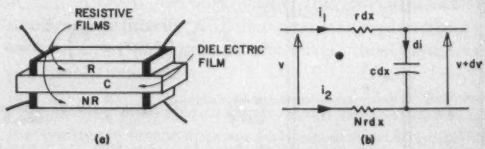


Fig. 1. Basic *R-C-NR* structure and equivalent circuit of an elemental section.

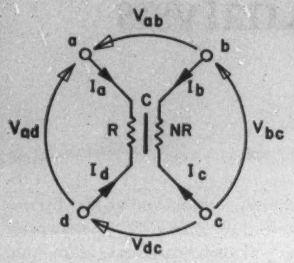


Fig. 2. Voltages and currents of the *R-C-NR* structure.

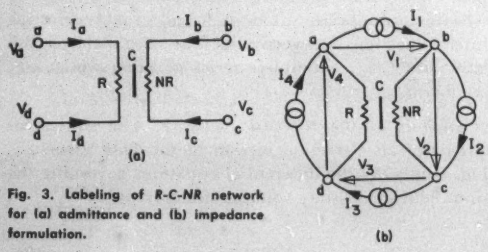


Fig. 3. Labeling of *R-C-NR* network for (a) admittance and (b) impedance formulation.

and currents applied to the terminals of the basic network leads to

$$V_{dc} = A + B \tag{7}$$

$$V_{ab} = Ae^{\theta} + Be^{-\theta} \tag{8}$$

$$V_{ad} = 1/(1+N)\,[A(e^{\theta} - 1) + B(e^{-\theta} - 1)] + G \tag{9}$$

$$V_{bc} = N/(1+N)\,[A(1 - e^{\theta}) + B(1 - e^{-\theta})] + G \tag{10}$$

for the voltages applied to the terminal pairs as shown in Fig. 2, and in which G is an arbitrary constant and

$$\theta = \alpha L = \sqrt{j\omega(1+N)RC} \tag{11}$$

where L is the total length of the films, $R = rL$ is the total resistance of the resistive film, and $C = cL$ is the total capacitance between resistive films. The terminal currents are given by

$$I_a = \frac{\theta}{(1+N)R}(Ae^{\theta} - Be^{-\theta}) + \frac{G}{R} \tag{12}$$

$$I_b = -\frac{\theta}{(1+N)R}(Ae^{\theta} - Be^{-\theta}) + \frac{G}{NR} \tag{13}$$

$$I_c = \frac{\theta}{(1+N)R}(A - B) - \frac{G}{NR} \tag{14}$$

$$I_d = -\frac{\theta}{(1+N)R}(A - B) - \frac{G}{R} \tag{15}$$

Indefinite Matrix Form of Solution. Equations 7 to 15 give the general solution for the basic 4-terminal networks in terms of the constants A, B, and G. If the network is to be specialized further, for example, by connecting a driving generator across a given pair of terminals and connecting or floating other terminals, these constants can be evaluated in terms of the driving generator for each configuration.

Alternatively, the constants A, B, and G can be eliminated once and for all and the terminal currents given in terms of the terminal voltages. Writing these relations by means of an indefinite admittance matrix yields the relation shown below in equation 16, where the labeling corresponds to that shown in Fig. 3(a). The indefinite admittance matrix makes possible the treatment of all terminals on an equal basis, and simplifies the derivation of parameters for particular configurations.[8]

For certain configurations an impedance rather than an admittance formulation facilitates the derivation

$$\begin{Vmatrix} I_a \\ I_b \\ I_c \\ I_d \end{Vmatrix} = \frac{1}{(1+N)R} \begin{Vmatrix} \frac{\theta}{\tanh\theta} + N & 1 - \frac{\theta}{\tanh\theta} & \frac{\theta}{\sinh\theta} - 1 & -\frac{\theta}{\sinh\theta} - N \\ 1 - \frac{\theta}{\tanh\theta} & \frac{\theta}{\tanh\theta} + \frac{\theta}{N} & -\frac{\theta}{\sinh\theta} - \frac{\theta}{N} & \frac{\theta}{\sinh\theta} - 1 \\ \frac{\theta}{\sinh\theta} - 1 & -\frac{\theta}{\sinh\theta} - \frac{1}{N} & \frac{\theta}{\tanh\theta} + \frac{\theta}{N} & 1 - \frac{\theta}{\tanh\theta} \\ -\frac{\theta}{\sinh\theta} - N & \frac{\theta}{\sinh\theta} - 1 & 1 - \frac{\theta}{\tanh\theta} & \frac{\theta}{\tanh\theta} + N \end{Vmatrix} \begin{Vmatrix} V_a \\ V_b \\ V_c \\ V_d \end{Vmatrix} \tag{16}$$

$$\begin{Vmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{Vmatrix} = \frac{R}{\theta} \begin{Vmatrix} \frac{N+1}{\tanh\theta} & -N\tanh\frac{\theta}{2} & -\frac{N+1}{\sinh\theta} & -\tanh\frac{\theta}{2} \\ -N\tanh\frac{\theta}{2} & \frac{N}{N+1}\left(\theta + 2N\tanh\frac{\theta}{2}\right) & -N\tanh\frac{\theta}{2} & -\frac{N}{N+1}\left(\theta - 2\tanh\frac{\theta}{2}\right) \\ \frac{N+1}{\sinh\theta} & -N\tanh\frac{\theta}{2} & \frac{N+1}{\tanh\theta} & -\tanh\frac{\theta}{2} \\ -\tanh\frac{\theta}{2} & -\frac{N}{N+1}\left(\theta - 2\tanh\frac{\theta}{2}\right) & -\tanh\frac{\theta}{2} & \frac{1}{N+1}\left(N\theta + 2\tanh\frac{\theta}{2}\right) \end{Vmatrix} \begin{Vmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{Vmatrix} \tag{17}$$

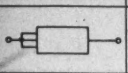
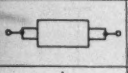
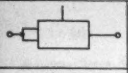
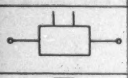
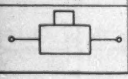
ONE-PORT CONFIGURATION	NUMBER OF ONE-PORTS	R-C-NR SYMMETRY FACTOR	R-C-NR ONE-PORTS
	4	4	1
	3	1	3
	12	4	3
	6	2	3
	6	2	3

Fig. 4. Unique one-ports obtained from a 4-terminal network.

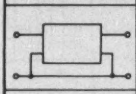
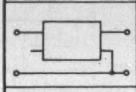
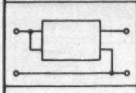
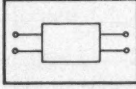
TWO-PORT CONFIGURATION	NUMBER OF TWO-PORTS	R-C-NR SYMMETRY FACTOR	R-C-NR TWO-PORTS
	6	2	3
	12	4	3
	12	4	3
	3	1	3

Fig. 6. Unique two-ports obtained from a 4-terminal network.

and is shown in equation 17, where the labeling corresponds to that shown in Fig. 3 (b).

If an indefinite impedance matrix is used, the voltages and currents must be taken as port, or terminal-pair quantities.

CATALOG OF SUBNETWORKS

THE OPERATIONS for indefinite matrices developed in the appendix will now be applied to identify all unique subnetworks resulting from the *R-C-NR* 4-terminal network derived in the previous section. The symmetry of the *R-C-NR* network will be shown to result in 13 one-ports and 12 two-ports. Although interchanging *R* and *NR* for nonsymmetrical networks will yield slightly different network functions, the actual configuration of these networks is not considered separately. This is equivalent to a definition of a unique network as one in which an interchange of input and output ports does not constitute another network.

Network Code. A network code has been devised to indicate the operations necessary to derive the one-port and two-port networks from the basic 4-terminal network. The method of coding is as follows: Each network is assigned a serial group of four quantities. The first one of the serial indicates the conditions of terminal *a*, the second indicates the conditions of terminal *b*, etc.

These quantities are:

1 – measured terminal
2 – measured terminal different from 1
0 – common reference terminal
f – terminal which is floating
c – terminal which is connected to another terminal and left floating (used in pairs)
1′ – measured terminal paired with 1
2′ – measured terminal paired with 2

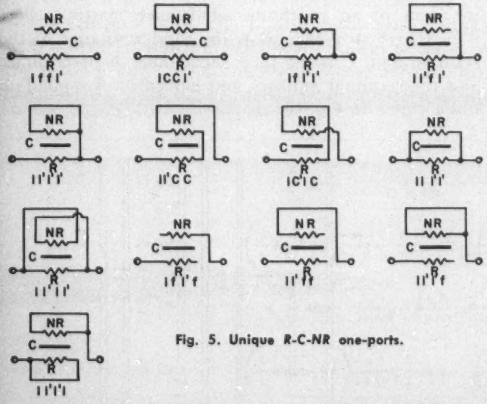


Fig. 5. Unique *R-C-NR* one-ports.

One-Ports. Five distinct types of one-ports result by applying successive matrix operations on the indefinite impedance or admittance matrix. Fig. 4 shows each type with the corresponding number of unique one-ports obtainable by elementary combinational rules. The symmetry of an *R-C-NR* network reduces each type by a factor of 4 or 2 or 1 according to the inherent symmetry of the *R-C-NR* network. The resultant 13 unique one-ports are explicitly drawn in Fig. 5, giving the appropriate code which identifies the one-port.

Two-Ports. Two-ports may be either 3-terminal or 4-terminal (bridge) networks. Fig. 6 catalogs each type with the corresponding number of unique two-ports. The symmetry factor for *R-C-NR* two-ports may be 4 or 2 or 1; thus, a total of 12 unique two-ports results. Using the results in Fig. 6, the unique two-ports with appropriate codes can then be drawn at once as shown in Fig. 7. Two successive matrix operations are required to derive the network characteristics of each two-port with the aid of the indefinite matrix coefficients of the *R-C-NR* network. Since this investigation is concerned primarily with network techniques, the results will not be catalogued; however, they have been presented elsewhere.[7]

Symmetry and Redundance. Some interpretation of the symmetry factor appears to be in order. Although a rigorous demonstration is considered beyond the scope of this investigation, several useful rules can be stated:

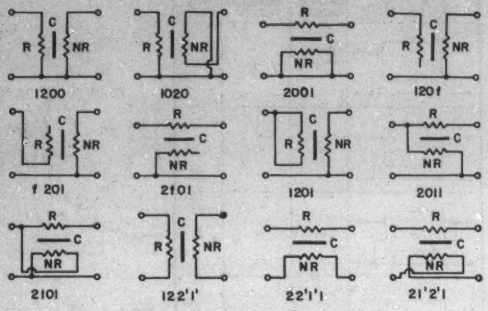


Fig. 7. Unique *R-C-NR* two-ports.

1. The symmetry factor gives a correlation between the symmetry of the general configuration and the symmetry of the specific network under consideration.

2. If the symmetry factor is high, the specific network introduces a high degree of redundance.

3. If the symmetry of the original network is high, the symmetry of the derived subnetwork is low, inasmuch as the generated subnetwork introduces less change, no matter how symmetrical it is.

4. If the original network is completely symmetrical, the symmetry factor is equal to the total number of subnetworks of each type.

5. If the original network is completely asymmetrical, the symmetry factor is equal to unity.

THE *C-R-NC* NETWORK

IN THE SAME MANNER that an *R-C-NR* network is defined as consisting of a dielectric film sandwiched by two resistive films, a *C-R-NC* network may be defined as consisting of a resistive film sandwiched by two dielectric films. The structure of the *C-R-NC* network is illustrated in Fig. 8 (a), with the proposed electrical symbol in Fig. 8 (b).

Analysis. The *C-R-NC* network may be considered as composed of a cascade of infinitesimal *R-C* elements shown in Fig. 9. On a per-unit-width basis, r is the resistance per unit length of the resistive film, c is the capacitance per unit length between the resistive film and the top conducting layer, and NC is the capacitance per unit length between the resistive film and the bottom conducting layer.

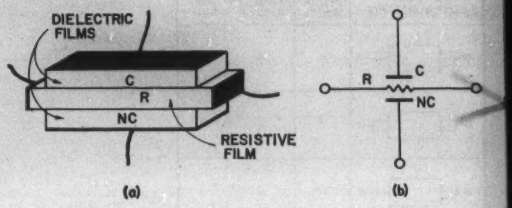


Fig. 8. Structure and electrical symbol of the C-R-NC network.

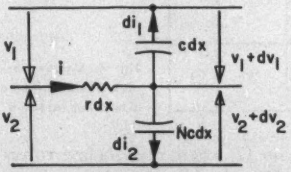


Fig. 9 (*left*). Elemental circuit of C-R-NC network. Fig. 10 (*right*). Terminal voltages and currents of C-R-NC network.

Assuming r, c, and N constant, the differential equations for the voltage and current of the *C-R-NC* network under steady-state sinusoidal excitation are

$$\frac{d^2i}{dx^2} = j\omega c\,(1+N)ri \quad \text{and} \quad \frac{dv_1}{dx} = \frac{dv_2}{dx} = -ir$$

with the solutions

$$i = A\epsilon^{\alpha x} + B\epsilon^{-\alpha x} \quad \text{and}$$

$$v_1 = (-r/\alpha)\,(A\epsilon^{\alpha x} - B\epsilon^{-\alpha x}) + D_1$$

$$v_2 = (-r/\alpha)\,(A\epsilon^{\alpha x} - B\epsilon^{-\alpha x}) + D_2$$

where A, B, D, and D_2 are arbitrary constants and $\alpha = \sqrt{j\omega\,(1+N)rc}$. Notice the similarity between these equations and those for the *R-C-NR* network.

Matrix Representation. An identical procedure to that used for the *R-C-NR* network can now be used to evaluate the arbitrary constants of the above equations in terms of the applied voltages and currents. It is then found by straightforward manipulation that the terminal voltages and the terminal currents can be written in terms of an indefinite admittance matrix, where $\theta = \sqrt{j\omega\,(1+N)RC}$, R is the total resistance of the resistive film, C is the total capacitance between films, and the terminal voltages and currents correspond to those shown in Fig. 10:

$$\begin{Vmatrix} I_a \\ I_b \\ I_c \\ I_d \end{Vmatrix} = \frac{j\omega C}{\theta} \begin{Vmatrix} \frac{N+1}{\tanh\theta} & -N\tanh\frac{\theta}{2} & -\frac{N+1}{\sinh\theta} & -\tanh\frac{\theta}{2} \\ -N\tanh\frac{\theta}{2} & \frac{N}{N+1}\left(\theta+2N\tanh\frac{\theta}{2}\right) & -N\tanh\frac{\theta}{2} & -\frac{N}{N+1}\left(\theta-2\tanh\frac{\theta}{2}\right) \\ -\frac{N+1}{\sinh\theta} & -N\tanh\frac{\theta}{2} & \frac{N+1}{\tanh\theta} & -\tanh\frac{\theta}{2} \\ -\tanh\frac{\theta}{2} & -\frac{N}{N+1}\left(\theta-2\tanh\frac{\theta}{2}\right) & -\tanh\frac{\theta}{2} & \frac{1}{N+1}\left(N\theta+2\tanh\frac{\theta}{2}\right) \end{Vmatrix} \begin{Vmatrix} V_a \\ V_b \\ V_c \\ V_d \end{Vmatrix}$$

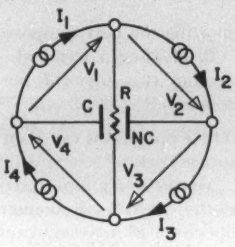


Fig. 11. Port voltages and currents of the C-R-NC network.

The similarity between the indefinite admittance matrix of the *C-R-NC* network and the indefinite impedance matrix of the *R-C-NR* network should be noted. These two matrices are identical if R is replaced by $j\omega C$ and $j\omega C$ is replaced by R. It is seen that θ remains unchanged. Furthermore, since it is shown in the appendix that the transformation from admittance to impedance is identical with the transformation from impedance to admittance except for a change in labeling, we can immediately write the indefinite impedance matrix (shown at the bottom of the page) of the *C-R-NC* network as being that of the indefinite admittance matrix of the *R-C-NR* network, replacing R by $j\omega C$ and $j\omega C$ by R. The voltage and currents correspond to those shown in Fig. 11.

In general, it is seen that a duality exists between the *R-C-NR* network and the *C-R-NC* network in that R is replaced by $j\omega C$, $j\omega C$ is replaced by R, admittance is replaced by impedance, and terminals are replaced by ports. Thus, open-circuit voltage transfer functions for the *R-C-NR* network become short-circuit current transfer functions for the *C-R-NC* network.

FREQUENCY IMAGE NETWORKS

IN THE TWO PREVIOUS SECTIONS, *R-C-NR* and *C-R-NC* networks were examined and were shown to be voltage-current duals. In Fig. 12, the quantities which replace each other in the description of these networks are shown.

NC-R-C and NR-C-R Networks. In addition to the voltage–current duals, Fig. 12 also shows two networks with properties which are frequency images to those of the *R-C-NR* and *C-R-NC* networks. These networks are obtained by replacing resistance with capacitance and capacitance with resistance in the elemental circuits of the *R-C-NR* and *C-R-NC* networks. By cascading a large number of elemental circuits, the distributed parameter networks of the type *NC-R-C* and *NR-C-R* are obtained. An electrical symbol for these networks is difficult to draw to correspond to these electrical properties, and has not been selected. Although these networks have not been realized to date, because materials with the desired electrical properties have not yet been discovered, it is instructive to examine their anticipated performance.

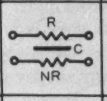
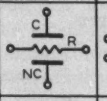
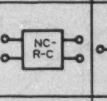
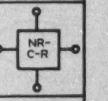
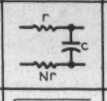
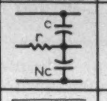
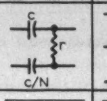
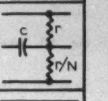
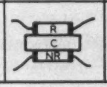
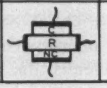
	R-C-NR	C-R-NC	NC-R-C	NR-C-R
NETWORK				
ELEMENTAL CIRCUIT				
θ	$\sqrt{j\omega(1+N)RC}$	$\sqrt{j\omega(1+N)RC}$	$\sqrt{(1+N)/j\omega RC}$	$\sqrt{(1+N)/j\omega RC}$
DUAL QUANTITIES	R	$j\omega C$	$1/j\omega C$	$1/R$
	$j\omega C$	R	$1/R$	$1/j\omega C$
	Z	Y	Z	Y
	Y	Z	Y	Z
	TERMINALS	PORTS	TERMINALS	PORTS
	PORTS	TERMINALS	PORTS	TERMINALS
STRUCTURE				

Fig. 12. Comparison of networks.

Frequency Image Characteristics. The indefinite admittance and impedance matrices of the *NC-R-C* network are obtained from those of the *R-C-NR* network by replacing R with $1/j\omega C$ and $j\omega C$ with $1/R$. The frequency variable θ is changed from $\sqrt{j\omega(1+N)RC}$ to $\theta = \sqrt{(1+N)/j\omega RC}$, demonstrating that these two networks have transfer functions which are frequency images on a log frequency scale reflected about the axis $\omega RC = -1$. The reflection axis can be changed from $\omega RC = -1$ to $\omega RC = +1$ by noting that the

$$\begin{Vmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{Vmatrix} = \frac{1}{j\omega(1+N)C} \begin{Vmatrix} \frac{\theta}{\tanh\theta}+N & 1-\frac{\theta}{\tanh\theta} & \frac{\theta}{\sinh\theta}-1 & -\frac{\theta}{\sinh\theta}-N \\ 1-\frac{\theta}{\tanh\theta} & \frac{\theta}{\tanh\theta}+\frac{1}{N} & -\frac{\theta}{\sinh\theta}-\frac{1}{N} & \frac{\theta}{\sinh\theta}-1 \\ \frac{\theta}{\sinh\theta}-1 & -\frac{\theta}{\sinh\theta}-\frac{1}{N} & \frac{\theta}{\tanh\theta}+\frac{1}{N} & 1-\frac{\theta}{\tanh\theta} \\ -\frac{\theta}{\sinh\theta}-N & \frac{\theta}{\sinh\theta}-1 & 1-\frac{\theta}{\tanh\theta} & \frac{\theta}{\tanh\theta}+N \end{Vmatrix} \begin{Vmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{Vmatrix}$$

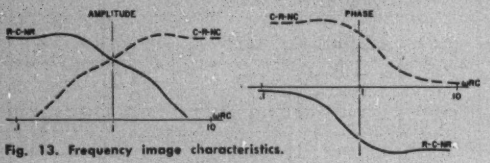


Fig. 13. Frequency image characteristics.

magnitude of the transfer function is an even function of ω and thus is unaffected by the change, but that the phase is an odd function of ω and thus changes sign. These frequency image characteristics are illustrated in Fig. 13.

In the same way, the *NR-C-R* network can be shown to be the frequency image of the *C-R-NC* network. Furthermore, since the *R-C-NR* and *C-R-NC* networks are voltage–current duals, so are the *NC-R-C* and *NR-C-R* networks. These characteristics are summarized in Fig. 12.

CONCLUSIONS

In the analysis of microsystems electronics circuits with distributed parameters, the indefinite admittance and impedance matrices provide a versatile and effective tool. These matrices may be used in a systematic derivation of subnetworks obtained by imposing various constraints on the terminal and port variables of the general network. Novel network functions can thus be obtained from such subnetworks.

By showing that the same transformation generally can be used to transform an admittance to an impedance (i.e. terminal to port) formulation as is used to transform an impedance to an admittance formulation, the principle of duality can be effectively employed. In addition, *NC-R-C* and *NR-C-R* networks have been postulated with frequency characteristics which are images to those of the *R-C-NR* and *C-R-NC* networks.

Appendix

The indefinite admittance matrix and indefinite impedance matrix are admirably suited for investigating circuit functions of subnetworks. Each row and column of an indefinite admittance matrix corresponds to a terminal current and a terminal voltage respectively, and each row and column of an indefinite impedance matrix corresponds to a port voltage and port current, respectively. Thus, all terminals and all ports (and the matrix manipulations involving these terminals and ports) are treated on an equal basis.

A complete duality exists between an indefinite admittance and an indefinite impedance formulation.[10] This duality will be emphasized in the following development, in which an indefinite admittance matrix analysis is paralleled with an indefinite impedance matrix analysis.

Subnetworks. Subnetworks are generated from a given network by applying one or more of the following two operations:

1. Connecting two terminals, which is equivalent to shorting the port composed of those two terminals

2. Floating a terminal, which is equivalent to connecting two adjacent ports having this terminal in common.[11]

These operations can then be applied successively to a subnetwork to generate further subnetworks.

Matrix operations corresponding to the two operations described are summarized in Table I. The matrix operation of inversion consists of setting the independent variable equal to zero and subsequently eliminating the corresponding dependent variable. The matrix operation of addition simply means adding the two independent variables affected and setting the two corresponding dependent variables equal to each other and thereby eliminating one of them. Table I exhibits the duality in both the terminal and port formulation as well as in the admittance and impedance operations.

A third operation added to Table I makes one of the independent variables the reference variable. This is achieved by setting this variable equal to zero and is equivalent to crossing off the corresponding row and column in the matrix.

Impedance and Admittance Matrices. It is often desirable to express the elements of the indefinite admittance matrix in terms of the elements of the indefinite impedance matrix and vice versa. It will be shown that a single transformation is sufficient to cover both cases, provided that ports and terminals are labeled appropriately. This transformation is:

$$\begin{Bmatrix} Z \\ Y \end{Bmatrix} = C^* \left[U_4^* \begin{Bmatrix} Y \\ Z \end{Bmatrix} U_4 \right]^{-1} C$$

where C^* and U_4^* are the transpose of C and U_4, respectively. The connection matrix C relates port and terminal quantities, and the matrix U_4 defines a unit matrix with the fourth column crossed off.

Connection Matrix. The variables

$$I_T = \begin{Vmatrix} I_a \\ I_b \\ I_c \\ I_d \end{Vmatrix}, \quad V_T = \begin{Vmatrix} V_a \\ V_b \\ V_c \\ V_d \end{Vmatrix}, \quad I_P = \begin{Vmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{Vmatrix}, \quad V_P = \begin{Vmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{Vmatrix}$$

Table I. Matrix Operations for Subnetwork Generation

Operation on Network	Set Equal to Zero	Set Equal to Each Other	Operation on Terminals	Operation on Ports	Operation on Admittance Matrix	Operation on Impedance Matrix
Short	Port Voltage	Terminal Voltage	Connect	Short	Add Rows and Columns	Invert Row
Open	Terminal Current	Port Current	Float	Disconnect	Invert Row	Add Rows and Columns
Ground	Independent Variable		Used as Reference	Used as Reference	Cross Off Row and Column	Cross Off Row and Column

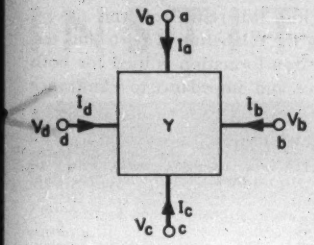


Fig. 14. Terminal voltages and currents for an admittance formulation.

define the indefinite matrices

$$Y = \begin{Vmatrix} Y_{aa} & Y_{ab} & Y_{ac} & Y_{ad} \\ Y_{ba} & Y_{bb} & Y_{bc} & Y_{bd} \\ Y_{ca} & Y_{cb} & Y_{cc} & Y_{cd} \\ Y_{da} & Y_{db} & Y_{dc} & Y_{dd} \end{Vmatrix} \quad \text{and} \quad Z = \begin{Vmatrix} Z_{11} & Z_{12} & Z_{13} & Z_{14} \\ Z_{21} & Z_{22} & Z_{23} & Z_{24} \\ Z_{31} & Z_{32} & Z_{33} & Z_{34} \\ Z_{41} & Z_{42} & Z_{43} & Z_{44} \end{Vmatrix}$$

where

$$I_T = Y\,V_T \quad \text{and} \quad V_P = Z\,I_P \tag{18}$$

The matrices Y and Z are made nonsingular by crossing off a row and a column; for example, the fourth row and the fourth column. The matrix operation which accomplishes this can be written as

$$Y' = U_4^*\,YU_4 \quad \text{and} \quad Z' = U_4^*YU_4 \tag{19}$$

Defining

$$I_T' = \begin{Vmatrix} I_a \\ I_b \\ I_c \end{Vmatrix}, V_T' = \begin{Vmatrix} V_a \\ V_b \\ V_c \end{Vmatrix}, I_P' = \begin{Vmatrix} I_1 \\ I_2 \\ I_3 \end{Vmatrix}, V_P' = \begin{Vmatrix} V_1 \\ V_2 \\ V_3 \end{Vmatrix}$$

we have

$$I_T' = Y'V_T' \quad \text{and} \quad V_P' = Z'I_P' \tag{20}$$

with

$$V_d = 0 \quad \text{and} \quad I_4 = 0$$

Inverting equation 20 yields

$$V_T' = (Y')^{-1}\,I_T' \quad \text{and} \quad I_P' = (Z')^{-1}\,V_P' \tag{21}$$

Figs. 5 and 7 show that terminal and port variables can be related by the connection matrices C_P and C_T:

$$V_P = C_P V_T' \qquad I_T = C_T\,I_P'$$

and

$$I_T' = C_P I_P \qquad V_P' = C_T\,V_T \tag{22}$$

where

$$C_P = \begin{Vmatrix} -1 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \end{Vmatrix} \quad \text{and} \quad C_T = \begin{Vmatrix} -1 & 1 & 0 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & -1 & 1 \end{Vmatrix}$$

Combining equations 19, 21, and 22 yields

$$V_P = C_P^*\,[U_4^*YU_4]^{-1}\,C_P\,I_P \quad \text{and} \quad I_T = C_T^*\,[U_4^*ZU_4]^{-1}\,C_TV_T \tag{23}$$

showing that

$$Z = C_P^*\,[U_4^*YU_4]^{-1}\,C_P \quad \text{and} \quad Y = C_T^*\,[U_4^*ZU_4]^{-1}\,C_T$$

Clearly, this result is independent of U_4; crossing off any other row and column would be equally well suited to transform the indefinite matrix to a definite matrix before the transformation operation is undertaken. The connection matrix depends of course, on the labeling of ports with respect to terminals.

Relabeling. In many cases it is advantageous to use the same transformation when converting the indefinite impedance matrix to the indefinite admittance matrix as when converting the indefinite admittance matrix to the indefinite impedance matrix (i.e., using $C_T = C_P$). This can be done provided a different labeling scheme is used for each transformation. For example, the transformation given in the left-hand side of equation 23 converts the labeling scheme shown in Fig. 14 to that shown in Fig. 15. However, beginning with the labeling scheme shown in Fig. 15 and using the same transformation (i.e., use C_T instead of C_P in the right hand side of equation 23), the labeling scheme which results is shown in Fig. 16. Comparing Fig. 16 with Fig. 14, it is seen that the terminal labeling is rotated clockwise by one terminal. Thus, starting with an indefinite admittance matrix of a network and transforming it to an indefinite impedance matrix, and then using the same transformation to change the indefinite impedance matrix to an indefinite admittance matrix would result in an indefinite admittance matrix that would correspond to the first if the rows and columns were advanced one place.

A few properties of the transformation matrices may be learned by performing the matrix transformation of indefinite admittance to indefinite impedance to indefinite admittance, in general terms. Beginning with an indefinite admittance matrix Y, the indefinite impedance matrix is given by

$$Z = C_T^*\,[U_i^*\,Y\,U_i]^{-1}\,C_T$$

where C_T need not yet be specified and U_i is the unit matrix with the ith column crossed off. This matrix is premultiplied and postmultiplied by U_k^* and U_k, respectively, where U_k is the unit matrix with its kth column crossed off, and the inverse taken.

At this point, to account for any changes in the labeling scheme, pre- and postmultiply by some matrix, such as E^* and E, respectively. If the transformation is completed by pre- and postmultiplying by C_P^* and C_P,

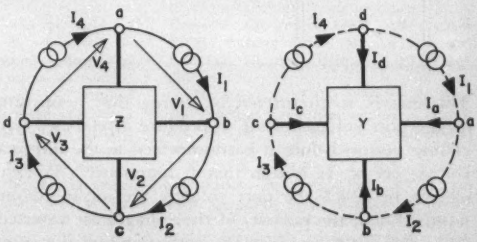


Fig. 15 (*left*). Port voltages and currents for an impedance formulation. Fig. 16 (*right*). Terminal currents after transformation from port currents.

respectively, the result should be the original matrix Y. Therefore,

$$Y = C_P^* E^* \{U_k^* C_T^* [U_i^* Y U_i]^{-1} C_T U_k\}^{-1} E C_P$$

Pre- and postmultiplying by U_i^* and U_i gives

$$U_i^* Y U_i = U_i^* C_P^* E^* \{U^* C_T^* [U_i^* Y U_i]^{-1} C_T U_k\}^{-1} E C_P U_i \quad (24)$$

To perform the inversion process indicated in the braces, note that while C_T and U_k individually have no inverses, the product $C_T U_k$ is necessarily square and must possess an inverse on physical grounds. Thus, equation 24 may be rewritten as

$$U_i^* Y U_i = \{(U_i^* C_P^*) E^* (C_T U_k)^{-1}\} (U_i^* Y U_i) \{(U_k^* C_T^*)^{-1} E (C_P U_i)\}$$

Since this equation must hold for all Y matrices and since the expressions in the brackets are transposes of each other, it is seen that the brackets must be unit matrices. Thus

$$(U_k^* C_T^*)^{-1} E (C_P U_i) = U$$

or

$$E(C_P U_i) = U_k^* C_T^* = (C_T U_k)^* \quad (25)$$

The matrices C_p, C_T, U_i, U_k, and E can thus assume any form as long as they satisfy equation 25. In practice, the form of the matrices depend to a great extent on the characteristics desired in the intermediate indefinite impedance matrix.

Returning now to the case of identical transformation for indefinite admittance and indefinite impedance matrices, equation 25 may be used to determine E and thus the change in labeling. Taking

$$C_P = C_T = \begin{Vmatrix} -1 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 1 & -1 & 0 \end{Vmatrix}$$

and

$$U_i = U_k = U_4 = \begin{Vmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{Vmatrix}$$

it is found that

$$E = \begin{Vmatrix} 0 & -1 & 0 \\ 0 & 0 & -1 \\ 1 & 1 & 1 \end{Vmatrix}$$

This matrix is interpreted by noting that it operates on the port voltage vector to produce a relabeled port voltage vector, before it is transformed to the terminal voltage vector. It is seen that it represents a labeling scheme in which the port voltages are advanced one terminal, and the polarity of the voltages are reversed. The matrix E^* performs the corresponding operation on the port current vector. The change in polarity is immaterial, since both voltages and currents change sign simultaneously. Thus, this result confirms the remarks made concerning the relabeling of ports and terminals when the same transformation is used for both admittance-to-impedance and impedance-to-admittance transformations.

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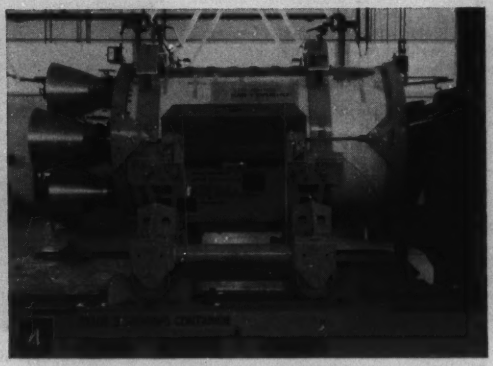
Lubricating with Air

A new concept in the use of air as a bearing lubricant is expected to result in wider applications for this type of minimum-friction bearing. The Boeing Aero-Space Division has announced the development of an externally pressurized step bearing, whose load-carrying shaft spins freely on a cushion of compressed air. The bearings operate effectively at cryogenic temperatures as well as high temperatures. Inventor C. R. Adams (*above*) is shown operating a step-type journal bearing with liquid nitrogen.

INSTITUTE ACTIVITIES

Hal Rumel

TOURISTS flock to L. D. S. (Mormon) Temple Square (*photo at left*) in the heart of Salt Lake City to visit this walled 10-acre plot which contains a spired temple that required 40 years to build, an oval-roofed tabernacle with a seating capacity of 8,000, an assembly hall, and a museum filled with pioneer relics. The 1961 Pacific General Meeting will take place August 23-25 in Salt Lake City. An Air



Force third stage Minuteman ICBM engine (*photo at right*) is being transported on a shipping container via a fork lift to a nearby transport truck, where it will leave from the Bacchus Works of the Hercules Powder Company for an off-plant test facility. This is typical of what visitors will see when they attend the AIEE inspection trip to the Hercules Powder Company during the Pacific General Meeting.

27 Technical Sessions Are Scheduled for Pacific General Meeting August 23-25

THE 1961 Pacific General Meeting of AIEE will take place August 23-25 in Salt Lake City, Utah. Registration will commence Tuesday evening, August 22, in the Hotel Utah which will be headquarters for the meeting. Hotel reservations are being accepted by the Hotel Facilities Committee, with F. O. Wald as chairman. Mr. Wald may be contacted in care of the Utah Power and Light Company, Box 899, Salt Lake City, Utah.

Since there will be no general session, 27 technical sessions will be scheduled morning and afternoon from Wednesday to Friday inclusive.

Technical Program Arranged

For Wednesday morning, August 23, sessions are scheduled on Reactor Instrumentation, Power System Communications, Computing Devices, and Relays. In the afternoon, the program continues with sessions on Special Instruments and Auxiliary Apparatus, Chemical Industry, Relays, Substations, and Computing Devices.

On Thursday morning, August 24, sessions are planned on Residential Electric Heating, Industrial and Commercial Power Systems, Wire Communication Systems, Materials Handling, and Reactor Operation. In the afternoon, sessions are slated on Industrial and Commercial Power Systems, System Engineering, Radio Communication Systems, Insulated Conductors, and Solid-State Devices.

The program on Friday, August 25, will open with sessions on Broadcasting, Industrial Control, Rotating Machinery, and Solid-State Devices. In the afternoon, the technical meeting will conclude with sessions on Feedback Control Systems, Transformers, and Solid-State Devices.

At the time of going to press, three inspection trips have been scheduled. The first trip will be on Wednesday to the copper mining, milling, smelting, and refining operation of the Kennecott Copper Corporation. The second trip, on Thursday, will be to the Columbia-Geneva Steel Division of the United States Steel Corporation at Geneva, Utah, and the third trip, on Thursday also, will be to the Hercules Powder Company at Bacchus, Utah, where work is under way on the third stage of the Minute Man missile and the second stage of the A2 Polaris missile.

A student luncheon will be held at Thursday noon, August 24, which will be followed by two meetings of students and counselors to discuss problems of mutual interest. On Tuesday evening, during the registration period, there will be a welcoming cocktail party held in the Hotel Utah. Wednesday noon, a welcoming luncheon will be held in the Lafayette Ballroom of the headquarters hotel. The featured speaker will be Dr. C. S. Winters of the General Motors Corporation. A cocktail hour will precede the main banquet on Thursday evening. Featured entertainment will be provided after the banquet.

Ladies Activities Planned

For the ladies, the program will begin Wednesday morning with a coffee hour which will be followed by a luncheon and fashion show at the Fort Douglas Country Club in Salt Lake City. On Thursday, brunch will be served at the Log Haven Resort located in Millcreek Canyon near Salt Lake City. Brunch will be followed by bridge and a program on flower arranging.

For Tuesday, August 22, the day before the official opening of the Pacific General Meeting, the Pacific Coast Relays Subcommittee is scheduling a full day of technical discussions. These discussion groups will be open to all members, as well as to the members of the Pacific Coast Relays Subcommittee. For further information, please see p. 546 in this issue of *Electrical Engineering* or contact M. A. Bostwick, Chairman, AIEE Pacific Coast Relays Subcommittee, at the Portland General Electric Company, Portland, Ore.

The members of the 1961 Pacific General Meeting Committee are: H. B. Hodgins, general chairman; R. A. Radford, co-chairman; J. A. McDonald, treasurer; J. N. Jones, secretary; F. C. Bates, finance, registration, and paper sales; R. K. Bertoch, program; V. E. Clayton, publicity; Mrs. P. G. Morse, ladies' activities; P. G. Morse, hospitality, trips, and sports; J. D. Stephens, entertainment; R. E. Stephenson, student activities; and F. O. Wald, hotel facilities.

AIEE Future Meetings

JECM&B-IFME International Conference on Medical Electronics*
Waldorf-Astoria Hotel
New York, N. Y.
July 16-21, 1961

Pacific General Meeting*
Hotel Utah
Salt Lake City, Utah
August 23-25, 1961

AIEE-IRE-ISA Joint Nuclear Instrumentation Conference
North Carolina State College
Raleigh, N. C.
September 6-8, 1961
(Final date for †TP—closed, ‡CP Syn.—closed, CPMs—July 3)

AIEE-ASME Engineering Management Conference
Hotel Roosevelt
New York, N. Y.
September 14-15, 1961
(Final date for †TP—closed, ‡CP Syn.—closed, CPMs—July 11)

Petroleum Industry Conference
Jung Hotel
New Orleans, La.
September 17-20, 1961
(Final date for †TP—closed, ‡CP Syn.—July 5, CPMs—July 14)

AIEE-ISA-IRE Industrial Electronics Conference
Bradford Hotel
Boston, Mass.
September 20-21, 1961
(Final date for †TP—closed, ‡CP Syn.—July 7, CPMs—July 17)

AIEE-ASME National Power Conference
St. Francis Hotel
San Francisco, Calif.
September 24-27, 1961
(Final date for †TP—closed, ‡CP Syn.—July 11, CPMs—July 21)

Middle Atlantic (Fall) Textile Conference
Barringer Hotel
Charlotte, N. C.
October 5-6, 1961
(Final date for †TP—July 21, ‡CP Syn.—Aug. 4, CPMs—Aug. 15)

AIEE-IRE-EIA-SMPTE National Electronics Conference
Sherman Hotel
Chicago, Ill.
October 9-11, 1961
(Final date for †TP—July 11, ‡CP Syn.—July 26, CPMs—Aug. 4)

Fall General Meeting
Statler-Hilton Hotel
Detroit, Mich.
October 15-20, 1961
(Final date for †TP—closed, ‡CP Syn.—July 27, CPMs—Aug. 11)

Machine Tools Conference
Faust Hotel
Rockford, Ill.
October 16-18, 1961
(Final date for †TP—July 18, ‡CP Syn.—Aug. 2, CPMs—Aug. 11)

NOTICE TO AUTHORS

Strict compliance with the "Author's Guide" will save you time, delays, and unnecessary correspondence. For a copy, write to E. C. Day, 33 West 39 St., New York 18, N.Y.

AIEE-IRE-U of Nebr. Biomedical Instrumentation and Engineering Conference
Sheraton-Fontenelle Hotel
Omaha, Nebr.
October 26-27, 1961
(Final date for †TP—July 28, ‡CP Syn.—Aug. 11, CPMs—Aug. 22)

Western Appliance Conference
Biltmore Hotel
Los Angeles, Calif.
November 6, 1961
(Final date for †TP—Aug. 8, ‡CP Syn.—Aug. 23, CPMs—Sept. 1)

Nonlinear Magnetics Conference
Statler-Hilton Hotel
Los Angeles, Calif.
November 6-8, 1961
(Final date for †TP—Aug. 8, ‡CP Syn.—Aug. 23, CPMs—Sept. 1)

AIEE-AIP Magnetism and Magnetic Materials Conference
Westward Ho Hotel
Phoenix, Ariz.
November 12-16, 1961
(Final date for †TP—Aug. 14, ‡CP Syn.—Aug. 29, CPMs—Sept. 8)

AIEE-IRE-ACM Eastern Joint Computer Conference
Sheraton-Park Hotel
Washington, D. C.
December 10-14, 1961
(Final date for †TP—Sept. 11, ‡CP Syn.—Sept. 26, CPMs—Oct. 6)

AIEE-IRE-ASQC National Symposium on Reliability Control
Statler Hilton Hotel
Washington, D. C.
January 9-11, 1962
(Final date for †TP—Oct. 11, ‡CP Syn.—Oct. 26, CPMs—Nov. 6)

Winter General Meeting
Hotel Statler
New York, N. Y.
January 28-February 2, 1962
(Final date for †TP—Oct. 30, ‡CP Syn.—Nov. 9, CPMs—Nov. 24)

AIEE-IRE-U of P International Solid-State Circuits Conference
February 15-16, 1962
(Final date for †TP—Nov. 17, ‡CP Syn.—Dec. 8, CPMs—Dec. 19)

South Central District Meeting
Hotel Peabody
Memphis, Tenn.
April 4-6, 1962
(Final date for †TP—Jan. 4, DPMs —Jan. 29)

Rubber and Plastics Industries Conference
Sheraton Hotel
Akron, Ohio
April 9-10, 1962
(Final date for †TP—Jan. 9, ‡CP Syn.—Jan. 24, CPMs—Feb. 2)

Great Lakes District Meeting
Hotel Van Orman
Fort Wayne, Ind.
April 18-20, 1962
(Final date for †TP—Jan. 18, DPMs —Feb. 9)

Mid-America District Meeting
Hotel Chase
St. Louis, Mo.
April 30-May 2, 1962
(Final date for †TP—Jan. 30, DPMs —Feb. 23)

Middle Eastern District Meeting
Hotel DuPont
Wilmington, Del.
May 7-9, 1962
(Final date for †TP—Feb. 6, DPMs —Mar. 2)

North Eastern District Meeting
Hotel Statler
Boston, Mass.
May 9-11, 1962
(Final date for †TP—Feb. 8, DPMs —Mar. 5)

AIEE-IRE Joint District Meeting
Erie, Pa.
May 14-16, 1962
(Final date for †TP—Feb. 13, DPMs —Mar. 9)

AIEE-ISA-ARS-IAS National Telemetering Conference
Sheraton-Park Hotel
Washington, D. C.
May 23-25, 1962
(Final date for †TP—Feb. 22, ‡CP Syn.—Mar. 9, CPMs—Mar. 19)

Summer General Meeting
Hotel Denver Hilton
Denver, Colo.
June 17-22, 1962
(Final date for †TP—Mar. 19, CPMs —April 11)

AIEE-AIChE-IRE-ISA-ASME Joint Automatic Control Conference
New York University
New York, N. Y.
June 27-29, 1962
(Final date for †TP—Mar. 29, ‡CP Syn.—April 13, CPMs—April 23)

IFIPS Congress
Munich, Germany
August 27-September 1, 1962
(Abstracts due Sept. 15)

*Final date for submitting papers—closed

†TP—Transactions Paper
‡CP Syn.—Conference Synopsis
CPMs—Conference Manuscript
DPMs—District Manuscript
(District Paper Synopses should be directed to the District Meeting Committee)

IN CHARGE of arrangements for the 1961 Fall General Meeting are: (*Front row, left to right*) H. M. Hess, treasurer; R. E. Bradstrom, secretary; W. H. Frank, general chairman; L. W. Clark, vice-chairman, and Mrs. R. E. Bradstrom, ladies activities. (*Back row*) O. W. Bowlus, registration; B. H. Schneider, hospitality; S. I. Whittlesey, publicity; C. R. Seibert, assistant treasurer; J. J. Fredrickson, junior past chairman, Michigan Section; J. C. Leffel, inspection trips; H. R. Armstrong, hotels, and A. P. Fugill, finance. Other members of the General Committee, not shown in this photo, are: E. R. Narum, entertainment, and F. Von Voightlander, general session.

50th Anniversary of Michigan Section To Be Observed at Fall General Meeting

THE AIEE Fall General Meeting, to be held in Detroit, Mich., October 15-20, will be highlighed by the 50th anniversary celebration of the Michigan Section, which is host of the meeting.

The Latin Quarter, one of Detroit's largest and finest dining facilities, will feature the Michigan Section 50th Anniversary Dinner-Dance on Tuesday, October 17. A social hour, beginning at 6:00 p.m., will precede the buffet dinner to be served at 7:00 p.m. Music and entertainment will be provided during the dinner by the Fenby-Carr Group and Belinda Blanchard. Music for dancing from 9:30 p.m. to 12:30 a.m. will be played by the Fred Netting orchestra, with Janie Palmer as vocalist. The entire evening will be priced at about $8.50 per person.

The Historians Committee of the Michigan Section has prepared a history of the Section, which records its events since its inception. The history provides a commemoration of the 50th Anniversary year and points out a unique organizational form recently adopted to meet increased diversification within the electrical profession. Responsible and efficient performance by the Section is also indicated. Copies of the history will be made available at the meeting to all who are interested in the successful performance of the Michigan Section.

Visitors to Detroit this Fall will notice many changes in the "Motor City." Two high-speed expressways have been completed and two more are under construction. The Civic Center in downtown Detroit is rapidly growing with the addition of Cobo Hall and Convention Hall to the Ford Auditorium, Veterans Memorial Building, and the City-County Building. A trip through the suburbs will show the rapid growth of home ownership and industry. Regular attractions in and near Detroit which welcome visitors include the Art Center with its library, the Art Institute, the Historical Museum and the Rackham Memorial housing the Engineering Society of Detroit, Wayne State University, Ford's Rotunda and Rouge Plant, Chrysler's many factories, Cadillac Motor, General Motors Building, Cranbrook, Belle Isle, and Rouge Park. For an excellent view of Detroit and the broadening experience of international travel, visitors may drive south through the Detroit-Windsor Tunnel to Canada and return over the Ambassador Bridge.

Many golf courses and marinas serve the sports-minded. Those attending the AIEE meeting may also have the opportunity to see the league-leading Detroit Tigers play.

Technical Paper Presented at Rocky Mountain Conference

W. M. Winslow (AM'43) and R. K. McCaig (AM '59) of the electric distribution engineering department of the Public Service Company of Colorado presented a technical paper at the Spring conference of the Rocky Mountain Electrical League at Boulder, Colo., on "A Spot Network from Radial Feeders." The paper is the result of several years of investigation and study at Stapleton Airport, Denver, to develop an outage-free electric distribution supply for the RAMAC reservation computer of United Air Lines.

The authors stated: "Spot network systems have applications in other locations on the electric distribution system and for different types of commercial loads such as hospitals, office buildings, and shopping centers. To these customers a prolonged outage often involves human safety and heavy loss of income or property. This investigation brings closer to practical realization the full utilization of specialized spot networks."

Mr. Winslow, who has been with Public Service Company 33 years, is head of the Underground Section of the electric distribution engineering department, and is a graduate of the University of Colorado. Mr. McCaig, who has been an engineer with Public Service 11 years, was recently promoted to meter engineer in the electric meter department, and is a graduate of the University of Denver.

TWO members of the Denver Section, AIEE, R. K. McCaig (*left*) and W. M. Winslow, presented a technical paper at the Spring conference of the Rocky Mountain Electrical League at Boulder, Colo. Both are employed by the Public Service Company of Colorado.

District 10 Annual Meeting Held

Ken Davies

PARTICIPATING in the AIEE District 10 Annual Meeting held May 16 in Montreal, Que., Canada, were: *(left to right)* H. O. Wilson, past chairman; Dr. R. Dupuis, vice-president, District 10, and Lionel Swift, incoming chairman.

Fosdick Survey Indicates Need for Educational Exposition

Before developing the 1962 Electrical Engineering Exposition, AIEE wanted to make sure there was a definite need for an across-the-board industry-wide exhibit. To this end, the well-known marketing research firm of John T. Fosdick Associates was engaged to conduct interviews with engineers attending the 1960 AIEE Winter General Meeting. The results of the Fosdick Survey indicated that such an educational exposition was needed and would be well attended by electrical and electronic engineers and scientists from across the country. For instance:

1. 70% of the engineers interviewed expressed a strong desire to see an exhibit of the industry's products and services.

2. 57% said they would definitely attend such an exhibit.

3. Of these, 43% have not attended any exhibit in the past year or so.

One more statistic: Of the many electric equipment manufacturers contacted, most expressed a strong interest in participating in such an exposition. With this assurance, the Electrical Engineering Exposition is certain to be the year's biggest marketing event.

The Exposition will run concurrently with the AIEE Winter General Meeting on January 29-February 2, 1962, at the New York Coliseum. Exhibitors may show their companies' progress in equipment and development to the more than 5,000 electrical and electronics engineers and scientists who will attend.

In industry, it is the engineer who decides what to buy, where to buy, and when, so exhibitors are advised not to miss this exciting marketing event for their companies' products. For further information, write to Reber-Friel Co., 117 South 17 St., Philadelphia 3, Pa.

Call Issued for Papers on Multivariable Control Systems

A call for papers has been issued for the Multivariable Control Systems Session at the 1962 AIEE Winter General Meeting. This session is sponsored jointly by the Computer and Logic Devices and the Linear Theory Subcommittees of the Feedback Control Systems Committee of AIEE.

The term "Multivariable Control Systems" here implies those systems with multiple inputs and outputs where interactions or cross-couplings are not negligible. This does include many of the more complex and larger systems being considered for control these days. The controllers for these systems are difficult to design mainly because of the number of variables being considered. Systematic methods utilizing machine computations are almost essential for both analysis and design purposes. In many instances, a control computer will be required to perform the many control and auxiliary tasks. As may be seen from the list below, the suggested subject areas for papers include some of these problems.

1. Design implications of the structuring method used for the multivariable system model.
2. Definitions of strength of interactions (cross-couplings) and the engineering use of such definitions.
3. Design of multivariable control systems subject to unmonitored disturbances.
4. Adaptive techniques for control of multivariable plants subject to large environmental excursions.
5. The use of computers to analyze multivariable systems, including the conversion of test results into model parameters.
6. The use of digital scientific computers to design controllers for multivariable plants to achieve specific types of control action, i.e., noninteraction.
7. Problems in applying computer control to plants with strong interactions.
8. Computer control techniques to maintain an optimum operating point for a multivariable system.

Inquiries concerning this session are invited by: R. A. Mathias, Westinghouse Research Laboratories, Beulah Road, Churchill Borough, Pittsburgh 35, Pa.

CORRECTION: The date of the 1963 North Eastern District Meeting to be held at Portsmouth, N. H., is incorrectly scheduled on p. 286 of the April issue of *Electrical Engineering*. The correct dates are May 21-23, 1963.

Relays Subcommittee To Hold Discussion August 22

The Pacific Coast Relays Subcommittee of AIEE has arranged a day of informal discussions of relay problems, to be held August 22, one day ahead of the AIEE Pacific General Meeting at Salt Lake City, Utah. Six broad subjects have been chosen for round-table discussion groups. Each topic will be presented by a panel of three or four, giving local preference for different solutions to the same problem, including operating experience to explain preferences. The subject will then be thrown open for discussion by the audience, which will be divided in groups of 10 or 12. Reporters will prepare a digest at each table to provide a summary after dinner.

The program will comprise the following six topics:

1. Distribution Protection. The value of selective protection will be compared to the value of sensitive ground fault protection.

2. Backup Protection. This will include conventional remote backup of line protection, local backup, relay backup, breaker backup, including backup protection against low-voltage faults in substations.

3. Reliability of Pilot Protection. Carrier, microwave, and wire circuits will be included. How reliable is the circuitry that you use? Can circuit simplifications (with admitted compromises) improve over-all operations?

4. Different Protection. What transformer sizes warrant harmonic restrained relays, sudden pressure relays? What

busses warrant voltage-type differential relays, linear couplers, or simple overcurrent with instantaneous trip?

5. Generator Protection. This will include differential protection, out-of-step protection, loss of field protection, and backup protection.

6. Oscillographs and Event Records. What value do these devices have in locating trouble and eliminating it?

Luncheon and dinner will be served to the group. All interested engineers are invited to take part. Guests will be welcome.

There will be no registration fee.

Student Paper Contest Held at South Dakota State College

Winners in the AIEE District 6 Student Paper Contest, held April 21 at South Dakota State College, Brookings, S. Dak., have been announced.

First, second, and third place winners were, respectively, Lyle Feisel of Iowa State University, Dennis Price of the South Dakota School of Mines and Technology, and D. L. Sheppard of the University of Colorado.

The contest took place during the District 6 Student Activities Committee meeting. An annual banquet was held in the evening. The next morning, the District Counselors and Student Chairman meetings were held. Those not attending the morning sessions participated in a tour of the Pathfinder Atomic Power Plant located near Sioux Falls, S. Dak.

Prof. K. E. Lindley, South Dakota State Student Branch counselor, and Glen Elliott, Branch chairman, were in charge of arrangements.

Extensive Program Is Planned for Conference on Medical Electronics

APPROXIMATELY 270 papers will be presented at the 4th International Conference on Medical Electronics, combined with the 14th Annual Conference on Electrical Techniques in Medicine and Biology, to be held July 16-21 at the Waldorf-Astoria Hotel in New York.

It is expected that plenary sessions will be on mathematical and biophysical models for stimulation and analyses, and biological effects on radio frequency and microwave fields. Round-table discussions are planned on computers for medicine and biology, perspectives in biomedical engineering science, electrocardiography, and acoustics and ultrasonics.

Special sessions are being arranged on monitoring of physiological variables in obstetrics, control systems in the human body, advances in recording, storage and retrieval techniques, gastrointestinal measurements, physiological instrumentation and education in biomedical engineering.

Exhibits Scheduled

In addition to the scientific sessions, there will be approximately 75 commercial exhibits and a number of individual scientific exhibits.

A program of tours and visits will be arranged to the following: Columbia-Presbyterian Medical Center, Columbia University, Columbia University Plains Nuclear Reactor, Veterans Administration Hospital, Brookhaven National Laboratories, Prudential Insurance Company of America Computer Center, and the International Business Machines Research Center.

A ladies' program of entertainment and sightseeing is planned. Papers are to be presented in English, French, German, and Russian, with two sessions per day translated.

The event is being sponsored by the Joint Executive Committee on Medicine and Biology of AIEE, the Institute of Radio Engineers, and the Instrument Society of America, and is under the auspices of the International Federation of Medical Electronics (IFME) organized by the Institute of Radio Engineers through its Professional Group on Bio-Medical Electronics.

Tentative Program Given

The program has been organized tentatively into simultaneous sessions, as follows:

Monday, July 17

Morning Registration and Opening

Afternoon Sessions

Electrical Techniques—Obstetrics, Gynecology
Computer Diagnosis
Electronic Images and Scanning Systems
Data Processing

Evening Sessions

Workshop (Informal Discussions). Perspectives in Bio-Medical Engineering—O. H. Schmitt

Tuesday, July 18

Morning Sessions

Mathematical Models
Recording, Storage, and Retrieval of Data
Magnetic Resonance and Electrical Impedance
Electrical Techniques—Obstetrics, Gynecology II

Afternoon Sessions

Biological Control Systems I
Sound and Related Techniques
Neurology, Ophthalmology, and Otology
Determination of Circulatory Parameters I

Evening Sessions

Workshop (Informal Discussions)
Computers—T. Sandel. Acoustics—J. Reid and W. Fry
IFME Council Meeting

Wednesday, July 19

Morning Sessions

Gastroenterology I
Recording, Storage, and Retrieval of Data II
Biological Control Systems II
Instrumentation I (Electrophysiology)

Afternoon Sessions

Instrumentation II (Telemetry)
Gastroenterology II
Biological Control Systems III
Determination of Circulatory Parameters II

Evening Session

IFME Plenary Session

Thursday, July 20

Morning Sessions

Biological Effects of Microwaves I (Athermal Aspects)

CONTESTANTS in the AIEE District 6 Student Paper Contest, held April 21 at South Dakota State College, were: (*Back row, left to right*) Lyle Feisel, Iowa State University; Joseph Floyd, University of Denver; Dennis Price, South Dakota School of Mines and Technology, and D. L. Sheppard, University of Colorado. (*Front row*) Dennis Nelson, University of Nebraska; Jack Benson, South Dakota State College, and James Felt, University of Wyoming.

Theory of Neural Functions and Organization
Electrophysiological Instrumentation I
Cardiac Output and Pacemakers

Afternoon Sessions

Determination of Circulatory Parameters III
Biological Effects of Microwaves II (Thermal Aspects)
Electrophysiological Instrumentation II
Cardiac Instrumentation

Evening Sessions

Workshop (Informal Discussions)
Recording Storage and Retrieval of Data—G. Webb, R. Schoenfeld. Electrocardiography—D. Geselowitz

Banquet

Friday, July 21

Morning Sessions

Radiology Techniques I
Biological Effects of Microwaves III
Electrocardiography
Instrumentation III

Afternoon Sessions

Heart Sounds and Pressure
Radiology Techniques II
Education and Documentation
Instrumentation IV

Evening Session

Conference Committee Meeting

Space Age Communications Discussed at San Diego Meeting

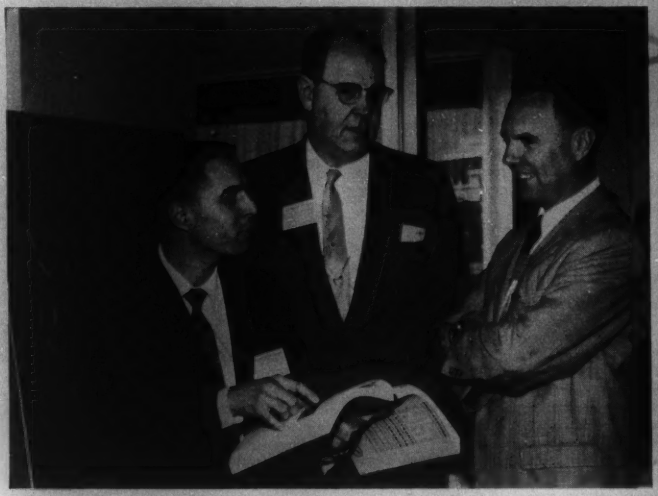
Highlighting the May 16 dinner meeting of the San Diego Section, AIEE, was a discussion of "Space Age Communications" by W. E. Quirk, vice-president and general manager, Southern Counties Area of the Pacific Telephone Company.

Mr. Quirk's very informative talk included an interesting discussion of the various approaches to satellite communication. He commented on the information gained from the very successful "Echo" project and explained in detail the part that the optical maser played in this phase of space communications. A model was used to demonstrate physically the way signals were bounced off Echo. He then discussed briefly the Bell System views on space communications given to the Federal Communications Commission and contrasted Bell's low-orbit approach to the high-orbit approach advocated by others.

A musical program featuring the "Bell Choraleers" was presented prior to the business portion of the meeting.

Cristof Studio
W. E. Quirk

Electronic Components Conference Held



TALKING about components in an informal session at the recent Electronic Components Conference in San Francisco, Calif., are: (*left to right*) H. C. Ross, general chairman; W. W. Wahlgren, Electro Engineering, a session author, and James Halloran, also of Electro, a session chairman. During the meeting, Mr. Halloran turned over his duties as AIEE Electronics Committee vice-chairman for the West to Mr. Ross.

AACC Reports to Sponsoring Societies on First IFAC Congress Held in Moscow

THE American Automatic Control Council (AACC), representing five sponsoring societies, organized American participation in the First International Congress of the International Federation on Automatic Control (IFAC), held June 27-July 7, 1960, in Moscow, USSR. Since that time, members of the AACC have tried to evaluate what they learned and what it implies in terms of the growing competition between Russia and the United States in the control field.

Affiliate societies of AACC comprise: AIEE, the American Society of Mechanical Engineers, the American Institute of Chemical Engineers, the Institute of Radio Engineers, and the Instrument Society of America.

Technical and plenary sessions were held during the week of June 27-July 2, 1960. The Congress was a sobering experience to the great majority of the 134 American delegates. The report to the sponsoring societies, which follows, describes the competitive picture as the AACC sees it, and the action the Council plans to take:

"The meetings were attended by 1,111 delegates (plus a large number of guests) from 29 countries—a total which included a remarkably large percentage of the leaders of the automatic control field. There were 274 technical papers presented during the 5 days devoted to technical sessions, with over 580 formal discussions and an average of 6-7 questions per presentation. The papers were presented in parallel sessions, with 11 running concurrently during a large portion of the week. In both plenary sessions simultaneous translation in French, German, English, and Russian was provided, while in the technical sessions material was usually presented in only the two languages, Russian and English (nonsimultaneous translation).

"As part of the Congress, a book display of more than 3,300 works on automatic control, unfortunately very few from the United States, was prepared by the Organizing Committee. During the week, 176 performances of 43 films on automatic control from 7 countries were presented, usually with translation. A variety of technical and general excursions were arranged by the hosts during the 10 days in Moscow, Leningrad, and Kiev.

"A dominant impression of the delegates from outside the USSR certainly concerned the whole-hearted support given to the Russian Organizing Committee by the Russian Government, the Academy of Science, and the Institute of Automation and Telemechanics. The Congress was opened by Vice-Premier Kosegin, and the government issued a special stamp in commemoration. The Congress itself was well organized, and all aspects from local

transportation to technical translation ran smoothly. The delegates were most impressively entertained, with particular high-lights the anticipated excellence of the Bolshoi ballet, the somewhat surprising elaborateness of the banquet, and finally the breath-taking impressiveness of the formal reception tendered on behalf of the Academy of Science in the Kremlin palace.

"The support exemplified by these arrangements seems to be the result of a remarkably strong emphasis of the Russian government on automation and automatic control—an emphasis which undoubtedly is partially rooted in military applications, but which seems to be strongly based upon a conviction of the potentialities of automation for not only increasing productivity, but also improving the life of the working man.

Russian Emphasis on Automatic Control

"The above idea is perhaps approximately summarized in the opening remarks by V. A. Trapeznikov, president of the Institute of Automation and Telemechanics—remarks which were echoed frequently throughout the week both at technical sessions and during individual conversations with the Russian engineers: 'Not only will automation raise productivity, but it will also radically change the very nature of labor.—Automation will help turn manual labor more and more into mental work . . . so that man's energy and vital strength directly involved in production may be utilized to an ever greater degree not for process control or —less so—for manual labor, but to produce and realize novel engineering ideas, such as would further relieve man of direct participation in production and would give him abundant life and more leisure. The higher labor productivity and expanded material production stimulated by automation will sharply improve the standards of living and reduce the working day to but a few hours in the near future.'

"The publicity given the Congress in the Russian press, the support apparent throughout from the government, and the intense interest in the USSR and the other Communist countries reflect the emphasis of the government on automatic control as an essential tool for the realization of a rapidly increasing automation of industry. For example, we were told that 7.5% of the USSR academicians were directly working in the automatic control field—not including related fields such as computer technology.

"The Russians are strong in research in fields important to the development of Automatic Control. These research efforts have roots that go far back in Russian Scientific history and they are being expanded through the Automatics and Telemechanics Branch of the Academy of Sciences of the USSR. The Russian weakness has been in application, but now they are rapidly building up institutes for automatic control in the various Republics under the Gosplan. For example, the Ukrainian Automatic Control Institute started in 1958, currently has 2,000 professional workers, and will have 6,600 people in it by 1965. As a consequence, we see a high current rate of progress in development, backed up by a sound scientific foundation for insuring its continuation.

"In the United States, the situation is quite different. The sum total of our application effort is vast, and industry is backing it up with a large amount of short range research in areas of proprietary interest. Thus, our competitive system is geared to translate quickly scientific knowledge into industrial accomplishment. However, industry is doing very little broad research of the kind needed to increase the fund of scientific understanding on which future progress depends. What is more, the universities are not filling the gap. Military research in the universities is subject to many of the same shortcomings as industrial research. Much of the remaining research effort in the universities is hampered by such factors as the difficulties of attracting and holding adequate personnel, the pressures to publish and the support that must be given to thesis work on problems that can be solved in a relatively short time. All of these factors mitigate against sound long-term research programs.

"The observations of the American delegation to the IFAC Congress indicate clearly that the real challenge is not in the present achievements of the USSR in the control field but rather in the high rate of progress there. If we are to maintain our leadership, the consensus of opinion is that we must step up our own rate of progress.

"Feeling as we do that we, in America, are well organized to exploit new knowledge, the spotlight focuses on the acquisition of such knowledge. This is the function of research and this is where we find that we are weak relative to the Russians in the automatic control field. The question, therefore, is what should be done to stimulate research in this and in related fields in this country.

"The long-term solution as we see it is largely educational. Our society as a whole does not yet appreciate the importance of research, and so is not prepared to offer the incentives, either social or economic, that would spur the needed growth. This makes it imperative that those of us who have concrete examples of such needs bring them to the attention of the leaders of our country.

"At the same time, much can be done within the scientific community to encourage the expansion of research and to insure that the programs undertaken are soundly conceived. Such effort will not only increase the productivity of our research but also make it worthy of support.

Plan of Action

"Clearly, this is a time for action. Furthermore, the American Automatic Control Council is in a unique position to supply technical leadership in this field. Therefore, we are setting up a Committee which will endeavor to: (1) examine the size and scope of the research effort required; (2) delineate areas and problems on which work is urgently needed; and (3) present our views to leaders in industry, in government, and in universities who can encourage and support such work and to groups capable of doing the actual research.

"We realize that the scope of this Committee is very broad, and that it extends beyond the technical areas in which we feel qualified. Therefore, to be effective, the Committee will try to work in cooperation with the engineering community at large, and with interested groups in the economic field, in the universities, in government, etc.

"We earnestly solicit your advice and support in this effort."

John C. Lozier
President, AACC

Cleveland Section Elects Officers

ATTENDING the annual dinner and election of officers at the AIEE Cleveland Section's May meeting were: *(left to right)* A. J. Hornfeck, Cleveland Section chairman; Mrs. Hornfeck; Mrs. J. S. Ewing, Cleveland Section Women's Auxiliary chairman, and R. A. Hunt, chairman of the annual dinner.

TEST CELL T-4 and the instrumentation used to record data on the GE J-85 turbojet engine are inspected by Miss Leah Herrman, David Adams, Barry Baker, and Sammy Newman of the Vanderbilt University AIEE Student Branch during their tour of the Rocket Test Facility of the Arnold Center. The J-85 power plant is used in the U. S. Air Force's Quail decoy missile and the T-38 supersonic trainer.

Student Members of AIEE Visit Air Force's Arnold Center in Tennessee

AN invitation to see and learn first-hand how various phases of electrical engineering are used in the operation of the high-speed high-altitude wind tunnels and propulsion test cells of the U.S. Air Force's Arnold Center was accepted by 64 student members of AIEE on April 15.

Jack Breed of ARO, Inc., operating contractor of this Air Force Systems Command installation and president of the Middle Tennessee Chapter of AIEE, extended the invitation to all student branches of AIEE in Tennessee as part of their educational program. Members from Tennessee Polytechnical Institute, Vanderbilt University, University of Tennessee branch, and Christian Brothers College were among those who attended.

The program included a briefing on the mission, capabilities, and accomplishments of the Arnold Center and a presentation on instrumentation development which described some of the work being accomplished in telemetry and high-speed photography to be used in a hyperballistic gun range. Miniaturized instrumentation is being developed for this facility which will be capable of withstanding acceleration forces of 250,000 *g* and which will record data on a model in free flight traveling at more than 18,000 mph.

Members of the Middle Tennessee Section of AIEE conducted the tour through each of the three major facilities and the power control station. During the tour of the von Karman Gas Dynamics Facility, the group inspected five of the nine tunnels which are capable of testing aerodynamic models of aircraft, missiles, and space vehicles in simulation of velocities of 1,000 to more than 20,000 mph and altitudes from sea level to more than 250,000 feet.

In the Rocket Test Facility, the students were shown the 11 high-altitude test cells which are engaged in testing most of this nation's high-priority propulsion systems. These test units are capable of simulating velocities up to 4,000 mph and altitudes from sea level to 150,000 feet for tests of both jet and rocket engines.

The students were also taken inside the 16-foot-square and 40-foot-long supersonic test section of the propulsion wind tunnel to view the 55-foot-diameter stagnation chamber and flexible steel nozzles. This facility is designed to test large or full-scale propulsion systems mounted in an aircraft or missiles as it would be in flight. Velocities from 500 to about 4,000 mph and altitudes from sea level to more than 200,000 feet can be simulated.

At the main power control station, the students were told that the Center used approximately 500 million kilowatt hours of electricity annually and is the fourth largest user of the Tennessee Valley Authority power. The power distribution system was explained in detail by AIEE members who are assigned to the Electrical Branch of the Technical Services Division of ARO, Inc.

The interest shown by this group has prompted the Middle Tennessee Section of AIEE to plan for future tours of this type for other Student Branches and to make a tour of the Arnold Center available to local Student Branches once every 2 years.

Symposium Planned on Industrial Electronics

An Industrial Electronics Symposium, sponsored by three engineering societies, has been planned for September 20-21 in the Bradford Hotel, Boston, Mass. Sponsors are AIEE, the Professional Group on Industrial Electronics of the Institute of Radio Engineers, and the Instrument Society of America.

A luncheon speaker will be C. Metcalfe, chairman of the Electronic Forum for Industry, London, England, a British organization recently formed to foster closer liaison between manufacturers and users of electronic equipment.

Highlighting the meeting will be a panel discussion among electronics experts and users of electronic equipment. The panel moderator will be William Vannah, an associate for advanced engineering with the Foxboro Company, Foxboro, Mass., and formerly chief editor of *Control Engineering*.

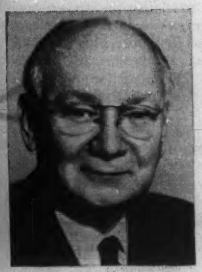
Technical sessions being planned on: Measuring Techniques for Industry, with Dr. C. W. Clapp, consulting physicist, instrument department, General Electric Company, as session chairman; Digital and Analog Techniques in Industry, with F. W. Atkinson, Owens-Corning Fiberglas Company, as chairman, and New Power Conversion Techniques, with C. H. Chandler, Gillette Safety Razor Company, as chairman.

At these sessions, technical papers will be presented on: Noncontact Measuring Techniques, Nondestructive Fault Testing, Moisture Measurement, Infrared and Chromatography Techniques, Analog and Digital Blending Techniques, Three-mode Controllers and Computers, A Novel System for Coupling a Turbine to a Variable Speed Drive with Silicon Controlled Rectifiers, Ultrasonic Machining Techniques, Industrial Applications of Thermoelectricity, and Electronic Sources of Industrial Heat.

Biomedical Conference Scheduled for October 26-27

A special technical conference on the Organization of Biomedical Instrumentation and Engineering in Universities and Hospitals will be held October 26-27 at the Sheraton-Fontenelle Hotel in Omaha, Nebr. The conference will be sponsored by the University of Nebraska, the Electrical Techniques in Medicine and Biology Committee of AIEE, and the Professional Group on Biomedical Electronics of the Institute of Radio Engineers (IRE).

Hosts for this conference will be the Nebraska Section of AIEE and the Omaha-Lincoln Section of IRE. The Program Committee chairman is Prof. Dennis LeCroisette of the Drexel Institute of Technology of Philadelphia.

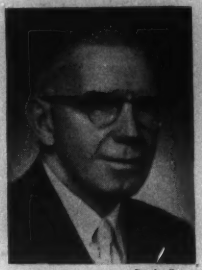


L. F. Hickernell

Philip Sporn

Agnes Baviello

K. S. Wyatt



Pach Bros.

W. J. Barrett

Colleges Honor AIEE Fellows for Their Services in Engineering Field

FOUR AIEE Fellows were among the prominent persons recognized recently by educational institutions with honorary doctorate degrees and awards.

L. F. Hickernell (AM '25, F '34), vice-president, engineering, Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y., received the doctor of engineering degree, Honoris Causa, at the June commencement of Polytechnic Institute of Brooklyn in Brooklyn, N. Y. He has served AIEE as president (1958-59), treasurer (1957), and director (1953-57).

The citation stated: ". . . Polytechnic sees in you a true example of a man dedicated to his profession, exemplified in your long labors in the service of the AIEE. . . ."

Honorary Doctorate Presented

Mount Allison University in Sackville, N. B., Canada, has conferred upon K. S. Wyatt (AM '32, F '48) the degree of doctor of science, Honoris Causa, at the university's Spring Convocation on May 16. In this way, the university expressed its appreciation of the service that Mr. Wyatt has given to the world in the scientific field.

Since 1941, Mr. Wyatt has been consultant to the president, Phelps Dodge Copper Products Corporation, New York City. His chief work has been the study of electrical insulation and its deterioration, with special reference to extra-high-voltage cables, up to 500,000 volts.

Philip Sporn (AM '20, F '30, Member for Life), president of American Electric Power Company, New York, N. Y., was the recipient of an honorary doctorate of technical sciences on March 8 at the Carnegie Endowment International Center in New York. The degree was conferred on Mr. Sporn by Avraham Harman, Israel Ambassador to the United States, at a special convocation of Technion-Israel Institute of Technology, arranged under the auspices of the American Technion Society. Mr. Sporn was honored by the Technion for his "pioneering activities in the efficient development of electric power and for his contributions to the investigation of possibilities for use of nuclear energy for electric power."

W. J. Barrett (M '36, F '50), special services engineer of the New Jersey Bell Telephone Company and former president of United Engineering Trustees, Inc. (UET), received the Allan R. Cullimore Award for Distinguished Service at the 45th commencement exercises of the Newark College of Engineering held June 8. Mr. Barrett was credited with responsibility, beginning in 1951, for persuading the nation's major engineering societies to consider building a multimillion-dollar Engineering Center now nearing completion on United Nations Plaza in New York.

In the AIEE, he has served as president (1957) and treasurer (1953-57). Mr. Barrett has been an AIEE representative on the Board of Trustees of UET since 1951 and also was president of UET (1955-58). Under his leadership, UET was given responsibility for the new national headquarters building for professional engineering societies.

The Cullimore Award, named after the first president of the Newark College of Engineering, is authorized by the college's board of trustees for recognition of unusual or distinguished service to the college, to the engineering profession, or to engineering education.

Society Participation Urged

In his commencement address, Mr. Barrett urged the graduates to participate actively in professional societies in order to keep abreast of new developments, exchange knowledge with their fellows, and discharge their responsibilities as members of the engineering profession. He stated:

"Technology is expanding at a terrific rate. How much greater will be our body of technical knowledge in, say, 10 years? And how will you keep up with the advances? Every engineer faces this problem of continuing education, and the answer that has evolved is the engineering society."

NEC Award Winners for Outstanding Papers Selected

Two scientists, one an associate member of AIEE, will be presented with the National Electronics Conference (NEC) annual awards of $500 each during the 1961 conference, October 9-11, at the International Amphitheatre, Chicago, Ill. The winners were selected for the best papers presented at the previous conference.

Winners are Dr. L. P. Huelsman (AM '52), formerly of Chicago, and an associate professor of electrical engineering at the University of Arizona, Tucson, Ariz., and Dr. R. M. Lerner, an assistant group leader in radar techniques at Lincoln Laboratory of the Massachusetts Institute of Technology (MIT).

Prof. Huelsman's paper, "Active RC Synthesis with Prescribed Sensitivities," was judged on the basis of scholarship, originality, significance, and clarity. He received his B.S. degree in electrical engineering from Case Institute of Technology and his M.S. degree in electrical engineering and Ph.D. degree from the University of California. Dr. Huelsman is a senior member of the Institute of Radio Engineers, and a member of Eta Kappa Nu, Sigma Xi, Phi Beta Kappa, and the American Society of Engineering Education.

Dr. Lerner's paper, "Modulation and Signal Selection from Digital Data Systems," was judged on selection, organization, and evaluation of material, plus scholastic level and clarity of presentation. The award to be presented to Dr. Lerner is for the best tutorial type of paper at the 1960 conference. Dr. Lerner received his B.S. and M.S. degrees in electrical engineering from Worcester Polytechnic Institute. He received his Sc.D. degree from MIT. Dr. Lerner is a member of Tau Beta Pi, Sigma Xi, the Acoustical Society of America, and the Institute of Radio Engineers.

M. E. Valkenburg is chairman of the 1961 Awards Committee.

R. J. Napolitan, general manager of NEC, announced that there is a great interest in the 1961 Conference and that all of the exhibition space at the coming convention has been reserved. Plans are now being made for speakers, meeting rooms, and decorations, which will be of an entirely electronic motif, in line with the convention theme.

Membership in the American Institute of Electrical Engineers, including a subscription to this publication, is open to most electrical engineers. Complete information as to the membership grade, qualifications, and fees may be obtained from Mr. N. S. Hibshman, Secretary, 33 West 39th Street, New York 18, N.Y.

AFIPS Formed To Organize Information Processing Sciences

A national voice for the computing profession, the American Federation of Information Processing Societies (AFIPS) came into being shortly after midnight on Wednesday, May 10, 1961. Delegates of the National Joint Computer Committee (NJCC), meeting at the Ambassador Hotel in Los Angeles, Calif., during the Western Joint Computer Conference, created this society of societies to fill the long recognized need of organizing the advancement and diffusion of knowledge of the information processing sciences at all levels and to all media.

Member societies of NJCC, which are also the founding societies of AFIPS, include AIEE, the Association for Computing Machinery (ACM), and the Institute of Radio Engineers (IRE).

Dr. W. H. Ware, of the computer sciences department at the Rand Corporation in nearby Santa Monica, Calif., was elected first chairman of AFIPS' Governing Board after the AIEE, ACM, and IRE had each selected four members for the board. The board will expand its membership as other qualified societies apply for membership and are accepted.

Immediate AFIPS objectives include making an orderly transition of business and authority from NJCC and formulation of plans for future joint computer conferences.

The AFIPS interim executive committee assisting Dr. Ware includes R. A. Imm of International Business Machines (IBM), AIEE; Dr. Harry Huskey, University of California, ACM, and Dr. A. A. Cohen, Remington Rand Univac, IRE.

Other members of the Governing Board are: AIEE—R. S. Gardner, the society's technical secretary; C. A. R. Kagan, Western Electric Company, and Dr. E. L. Harder, Westinghouse. ACM—J. D. Madden, System Development Corporation; Bruce Gilchrist, IBM, and Dr. Jack Moshman, Corporation Economic Industrial Research. IRE—Dr. Werner Bucholz, IBM; H. T. Larson, Ford Motor Company, and F. E. Heart, MIT Lincoln Laboratory.

IRE Becomes Co-Sponsor of Nonlinear Magnetics Conference

Co-sponsorship by the IRE (Institute of Radio Engineers) Professional Groups on Electronic Computers and Industrial Electronics has been officially announced for the 1961 Special Technical Conference on Nonlinear Magnetics. Because of IRE's decision to participate, Dr. Ted Bernstein, chairman of the Technical Program Committee, has extended the closing date for conference papers to August 8, 1961. Response to the initial request for technical papers has been excellent and, with the added IRE participation, an extremely successful conference is anticipated.

For further details concerning the 1961 Special Technical Conference on Nonlinear Magnetics, scheduled for November 6-8 at the Statler-Hilton Hotel in Los Angeles, Calif., contact Dr. Ted Bernstein at Space Technology Laboratories, P. O. Box 95001, Los Angeles 45, Calif.

American Power Dispatchers Elect Officers at Spring Meeting

New national officers of the American Power Dispatchers Association were elected at the Association's national Spring meeting held April 28-29 in Phoenix, Ariz., at the Salt River Power District's dispatch office.

J. L. Price, system dispatcher, Southern California Edison Company, was named president. Elected to the office of vice-president was J. T. Morcom, dispatcher, Salt River Power District; secretary, R. H. Renfro, system dispatcher, Southern California Edison Company; and treasurer, C. M. Merrell, chief dispatcher, City of Glendale, Calif., Power Department.

A conducted tour of the Inspiration Consolidated Copper Company mine in Miami, Ariz., was held Saturday, April 29.

H. C. Weed, vice-president and general manager of the Inspiration Consolidated mine, was guest speaker at the final dinner meeting held Saturday night at the Sands of Tempe hotel in Tempe, Ariz. Mr. Weed spoke to the group on the mining and production of the metal that is so essential to the electrical industry.

Licensing and Construction of Nez Perce Project Sought

O. W. Hurd (AM '36, F '58), managing director of the Washington Public Power Supply System (WPPSS), of Portland, Ore., rededicated the efforts of the Supply System to insure the early licensing and construction of the Nez Perce Project, when he spoke in San Antonio, Texas, on April 26 before the annual convention of the American Public Power Association.

Mr. Hurd reaffirmed the Supply System's belief in the superiority of the Nez Perce Project to "insure maximum development (of the Middle Snake River) in the public interest, low-cost power for load growth and industrial expansion, maximum utilization of the federal transmission grid system and an assured supply of power for the participating utilities at an increasingly attractive price for the revenue bond payout period and at a fraction of that cost thereafter."

WPPSS is representing 40 consumer-owned utilities in Oregon, Washington, and Idaho in its application for a license to build the Nez Perce Project on the Middle Snake River. Pacific Northwest Power Company, a combine of four private utilities, has an application pending before the Federal Power Commission also for the High Mountain Sheep Project.

Conference Papers Open for Discussion

Conference papers listed below have been accepted by AIEE *Transactions* and are now open for written discussion until July 26. Duplicate double-spaced typewritten copies of each discussion should be sent to E. C. Day, Assistant Secretary for Technical Papers, AIEE, 33 W. 39th St., New York 18, N. Y., on or before July 26.

60-1404 **Transmission Limitations Computed by Superposition.** *C. A. MacArthur*

61-39 **Controlled Temperature and Insulation Protection in the Operation of Power Transformers.** *E. B. Grace*

61-133 **The Trend to Single-Tank Oil Breakers for Subtransmission Voltages.** *E. B. Rietz*

61-135 **Vacuum Power Switches: Five Years of Field Application and Testing.** *H. C. Ross*

61-142 **A Basic Analysis of the Commutatorless Primitive Machines of Kron.** *Harit Majmudar*

61-173 **High-Frequency Iron Losses in Fractional-Horsepower Induction Motors.** *V. C. Shaneman*

61-236 **Leadville High-Altitude EHV Test Project**

Part III—Radio-Influence Investigations. *L. M. Robertson, W. E. Pakala, E. B. Taylor, Jr.*

Part IV—Conductors, Towers, Insulators, and Substations. *L. M. Robertson, D. H. Sandell, H. M. Walton, O. R. Huggins, J. C. Smith, R. G. Yerk, A. D. Lantz, Jr., J. E. O'Neil*

61-242 **Nondestructive Inspection of Cable Terminations and Splices by X-Ray Analysis.** *T. L. Bourbonnais, II*

Preprints may be purchased at 50¢ each to members, $1.00 to nonmembers, if accompanied by remittance or coupons. Please order by number and send remittance to: AIEE Order Department, 33 W. 39th St., New York 18, N. Y.

Los Angeles Section Elects Chairman for 1961-62

Prof. L. L. Grandi, professor of engineering, University of California at Los Angeles, has been elected chairman of the Los Angeles Section, AIEE, for the year 1961-62, beginning June 1, 1961. Outgoing chairman Robert Milmoe made the announcement at the Section's annual "Ladies Night" banquet which was held at Disneyland Hotel, Anaheim, Calif.

A registered professional engineer, Prof. Grandi served last year as vice-chairman of the Los Angeles Section. He is a graduate of the University of California, holds both the B.S. and M.S. degrees in electrical engineering, and is active in local and national engineering societies.

During his term of office, Prof. Grandi will be assisted by the following officers: Vice-Chairman—F. L. Goss, assistant engineer in charge of operation, Los Angeles Department of Water and Power; Secretary-Treasurer—W. S. Moody, manager, Application Engineering, General Electric Company; Director No. 1, Professional Development and Recognition—R. B. Kimball, application engineer, General Electric Company; Director No. 2, Technical Operations—H. L. Woodbury, electrical engineer, Glendale Public Service Department; Director No. 3, Technical Operations—J. K. Berger, member of technical staff, Hughes Aircraft Company; and Director No. 4, Administration—W. H. Wedel, staff engineer, Pacific Telephone Company.

Division Chairmen will be chosen by their own groups, and committee chairmen and committee members will be appointed.

Space Travel Is Discussed at Meeting of Johnstown Section

The Exploration and Utilization of Space was the subject of an address given at the annual dinner meeting on May 24 of the Johnstown Section, AIEE, by Dr. Harald Schutz, manager, Weapons System Engineering, and director, Astronautics Institute, Air Arm Division, Westinghouse Electric Corporation, Baltimore, Md.

Dr. Schutz stressed the importance of being able to maneuver at will in space. Engineering problems he has encountered in an analysis of space travel contain such items as propulsion, navigation, communications, human factors, and space science. Reliability problems are being met, he said, through molecular engineering, which enables scientists to reduce drastically the number of components in a missile or space vehicle.

Dr. Schutz listed five main reasons for the space race between the world powers: propaganda, military uses, economic advantages, population problems, and the innate drive to explore.

Paul Pasternak, the new section chairman, and other officers were inducted at the meeting. T. C. Pitzer, retiring chairman, was presented a gift by the section and a distinguished service plaque by the national organization.

Chairman's Gavel Changes Hands

TURNING over the chairman's gavel of the Denver Section, AIEE, to Prof. W. J. Hanna (*right*), associate professor of electrical engineering at the University of Colorado, is W. L. Smith, outgoing chairman of the section. Mr. Smith is the electric utility representative in the Rocky Mountain region for the Allis-Chalmers Manufacturing Company. Other officers of the Denver Section, which has more than 700 members, are: Vice-Chairman, F. E. Swain, U. S. Bureau of Reclamation; Secretary, A. M. Spaulding, Mountain States Telephone Company, and Treasurer, J. J. Springer, Public Service Company of Colorado.

Fellow Certificate Presented

Fred Tambling

HIGHLIGHTING the Akron Section Annual Ladies' Night meeting, held May 16 in the Sheraton Hotel, Akron, Ohio, was the presentation of an AIEE Fellow certificate to W. H. Sammis (*center*), president of the Ohio Edison Company, by J. H. Foote (*right*), past president of AIEE. W. H. Chase (*left*), vice-president of AIEE District 14, presented Mr. Sammis with a Fellow key on behalf of the Akron Section. C. L. Smith, president of the Cleveland Chamber of Commerce, addressed the meeting on "This Is a Great Area," in reference to the industrial potential of the Akron-Cleveland area. Section officers for 1961-62 also were elected at this meeting.

Engineering Technicians To Be Certified by NSPE Body

The establishment of an Institute for the Certification of Engineering Technicians (ICET) has been authorized by the National Society of Professional Engineers (NSPE). Purposes of the ICET are to: elevate the performance standards of engineering technicians, determine the competence of engineering technicians through investigations of voluntary candidates for certificates to be issued by the ICET, and issue certificates to engineering technicians who voluntarily apply.

The ICET is an examining and certifying body only, which will determine qualification for three classes of technician upon voluntary submission of credentials by a person seeking such recognition. ICET certification does not constitute a license to practice engineering.

Trustees are to be named to the ICET, which is now in the process of organization. The advice and assistance of other engineering or technical organizations will be solicited, and for this purpose an Advisory Council may be established to be composed of representatives of other engineering or technical organizations.

Additional information on the ICET may be obtained from A. C. Friel, chairman, Engineering Technicians Committee, National Society of Professional Engineers, 2029 K St., N. W., Washington 6, D. C.

AIEE PERSONALITIES

F. E. Anderson (AM '31), consulting electrical engineer in Northern and Central California and chief of the Mechanical-Electrical Section, Sacramento District, Army Corps of Engineers, has retired after 47 years of private and Federal service. He was responsible for the mechanical and electrical design features that went into the construction of Folsom Dam on the American River, Pine Flat Dam on the Kings River, and Isabella Dam on the Kern River. He directed design work for pumping plants now in operation at the Sacramento Signal Depot, McClellan and Mather Air Force Bases near Sacramento, Travis Air Force Base near Fairfield, Stead Air Force Base near Reno, and Sharpe General Depot near Stockton. Pumping facilities under construction at the Sacramento Deep Water Ship Channel Project were designed under Mr. Anderson's supervision. For the last 2 years, Mr. Anderson had been acting as special assistant to the corps' head designer in Sacramento.

J. N. Antonevich (AM '51) has been appointed director of ultrasonic research and development, Blackstone Corporation, Jamestown, N. Y. He has been assigned to directing development of new types of sonic equipment and exploring new applications for sonic energy. He was previously associated with Battelle Memorial Institute at Columbus, Ohio, as principal electrical engineer.

G. R. Archer (AM '54) has joined Compu-Dyne Corporation as general manager of their process Control Division located in Hatboro, Pa. Mr. Archer came to Compu-Dyne from the Budd Company where he was chief engineer of the Electronic Control Section.

J. C. Aydelott (M '32, F '48) of the General Electric Company's locomotive and car equipment department has been awarded a $1,000 prize for a technical paper on locomotive wheel slip. The award was made by Alco Products, Inc., at the recent Pan American Railway Congress. It was the second highest of 16 prizes made from a total of 161 papers. The paper, entitled "The Slippery Spot Concept of Wheel-to-Rail Adhesion and its Implications with Respect to Economical Locomotive Operation," was judged by the Congress as the best paper on the construction, operation, and modernization of diesel-electric locomotives. Mr. Aydelott's thesis is that wheel slip is caused by slippery patches of rail, and therefore can be controlled by checks only when the locomotive is actually on one of the patches. The system concept by Mr. Aydelott allows the train weight to be increased to meet average conditions. This new approach significantly increases the amount of useful work the locomotive can accomplish. Mr. Aydelott has served on the AIEE Land Transportation Committee (1941-61, chairman 1947-49).

John Cammarata (AM '52, M '55) has been named manager of product reliability for Arma Division, American Bosch Arma Corporation, Garden City, N. Y. For the last year, he was assistant chief engineer—operations.

L. H. Carson (AM '48, M '56) has been appointed chief engineer of the Transformer Division, Supreme Transformer Company, Chicago, Ill. Mr. Carson will concern himself with a variety of activities including the improvement of engineering design and performance of Supreme transformers.

R. M. Casper (M '40) has been appointed general manager, Power Equipment Division, Allis-Chalmers Manufacturing Company, Milwaukee, Wis. Mr. Casper, who is a vice-president of the company, has been general manager, Atomic Energy Division, since 1957.

J. B. Connelly (AM '47) has been appointed director of field engineering of Sperry Gyroscope Company, Division of Sperry Rand Corporation, Great Lake, N. Y. In his new position, Mr. Connelly will direct the world-wide activities of field engineers concerned with Sperry's diverse marine, aviation, military, and industrial products. Since 1956, Mr. Connelly has been superintendent of the company's Wichita, Kans., service area.

Student Branch Prize Paper Competition Held

WINNERS in the AIEE Middle Eastern District 2 Student Branch Prize Paper Competition, held April 28 at the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Pa., have been selected. Shown are: (*left to right*) H. M. Chandler, chairman, District 2 Student Activities Committee; J. P. Bevans, Johns Hopkins University, second prize winner for the paper, "A Random Number Generator"; R. G. Chapman, Jr., Princeton University, first prize winner with the paper, "Modified Coherer as a Bistable Element"; H. H. Sheppard, vice-president, District 2, and B. D. Dent and Lex Hughes, Lafayette College, joint third prize winners, for the paper, "Electric Chronometer."

G. F. Simmons (AM '51, M '59), formerly with General Electric Company, Rome, Ga., has joined Precision Transformer Corporation's engineering department. Mr. Simmons has taken full responsibility for the design and development of dry-type transformer lines.

D. D. Smith (AM '47, M '58) of Hampton, Va., and **T. E. Bowman** (AM '55) of Newport News, Va., have been named chairman and secretary, respectively, of the new Hampton Roads Section, AIEE, which embraces 18 Virginia counties. Mr. Smith has served on the AIEE Domestic and Commercial Applications Committee (1959-61).

F. V. Smith (AM '23, F '48, Member for Life), has been named senior partner of Sargent & Lundy, Chicago, Ill., consulting engineers. Mr. Smith was formerly general manager.

W. B. Snow (AM '25, M '34) has been named to the scientific staff of the Bissett-Berman Corporation. Mr. Snow was most recently a member of Space Technology Laboratories, Inc.

K. R. Van Tassel (AM '27) has been elected president of the A. B. Dick Company, Chicago, Ill. He joined the company in 1956 as executive vice-president.

A. P. Walker (M '54) has been appointed to the Cedar Rapids Division of Collins Radio Company, Cedar Rapids, Iowa. Mr. Walker, who was formerly manager of engineering for the National Association of Broadcasters is now responsible for the development activities of Collins commercial broadcasting and amateur radio product lines. He served on the AIEE Broadcasting Committee (1954-61).

A. J. Ward (AM '47, M '52), a marketing specialist, has been named to the staff of A. T. Kearney & Company. Prior to joining the Kearney organization, Mr. Ward was manager of market planning and service for the Sundstrand Aviation and Defense Products Division of the Sundstrand Corporation at Rockford, Ill.

R. T. Weil, Jr. (AM '32, M '44), head of the department of electrical engineering at Manhattan College, New York, N. Y., since 1945, has been appointed dean of the School of Engineering, effective July 1. Dean Weil has been a faculty member at Manhattan for 29 years. He has served the AIEE as vice-president of District 3 (1960-62), on the Board of Directors (1960-62), and as a member of the Finance Committee 1960-61).

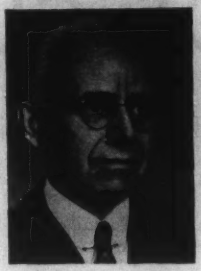
Albert Guida

R. T. Weil, Jr.

A. H. Wolfson (AM '58) has been appointed engineering proposals manager of the Data Systems Operations of Sylvania Electric Products Inc., Needham, Mass. In his new capacity, Mr. Wolfson will be responsible for directing all engineering proposal activity of the Data Systems Operations. He was formerly project engineer for an air-borne digital computer system in the data processing laboratory of Sylvania Electronic Systems' Waltham Laboratories, Waltham, Mass.

OBITUARIES

Ralph Waldo Atkinson (AM '09, M '14, F '28, Member for Life) of Westfield, N. J., consultant on high-voltage cables and power transmission, died May 17 at the age of 73. Mr. Atkinson retired in 1954 as director of research for the General Cable Corporation. Born June 16, 1887, in Smithland, Iowa, he studied at Iowa State College from which he obtained the B.S. degree in electrical engineering in 1906 and the electrical engineering degree in 1911. He was employed as engineering apprentice in 1906 by Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. In 1908, Mr. Atkinson became an assistant to the chief engineer of Standard Underground Cable Company, and in 1923 he was promoted to chief electrical engineer. When General Cable absorbed Standard Underground in 1929, he went to General Cable where he became director of High Tension Laboratories. In 1944, he was promoted to chief research engineer, and in 1952, director of research. He was the inventor of various methods dealing with manufacturing and testing of high-voltage cables. After his retirement in 1954, he served the company occasionally as a consultant. Mr. Atkinson was a scientific observer at the atomic tests at Bikini in 1946. He went to India in 1956 under the United States Technical Co-operation Program as head of the electrical engineering department of Sindri Institute, Bihar Institute of Technology, Sindri, India. The Atkinson Laboratory at Sindri was named in his honor. Iowa State College awarded him its Anson Marston Medal in 1951 for achievement in engineering, and in 1959 he was the recipient of the annual Chicago alumni Award of Merit. Mr. Atkinson was a member of the Engineers Club of New York, the American Association for the Advancement of Science, the American Standards Association, the American Society of Testing Materials, and the National Research Council. Mr. Atkinson served on the following AIEE Committees: Transmission and Distribution (1919-24), Power Transmission and Distribution (1924-30), Research (1933-41), Standards (1934-56), Board of Examiners (1945-61), Insulated Conductors (1954-61), and Dielectrics (1955-57). Plans are being made to establish a scholarship in his memory at Sindri Institute, and gifts may be made to this project.



R. W. Atkinson

Howard Austin Enos (AM '21, M '27, F '54, Member for Life), retired distribution engineer of the American Gas and Electric Service Corporation in New York, died recently at the age of 70. Born April 4, 1891, in Cheshire, Mich., Mr. Enos was educated at the University of Michigan from which he received the B.S. degree in electrical engineering in 1917. He had been associated with American Gas and Electric since 1924 in charge of the Distribution Engineering Section. He was responsible for the planning and supervision of the operation of distribution systems of the entire American Gas and Electric system.

Floid Merrill Fuller (AM '12, M '12, Member for Life), retired distribution engineer for the Pennsylvania Power and Light Company, died April 20. Born September 4, 1883, in Scranton, Pa., he studied at the Massachusetts Institute of Technology from which he received degrees in mechanical and electrical engineering in 1906 and 1908, respectively. He was a member of the National Society of Professional Engineers, the Engineers Club of the Lehigh Valley, and the American Society of Mechanical Engineers.

Victor P. Oldfeild (M '51), engineer-in-charge, Government of India Overseas Communications Service, Madras, India, died recently. Mr. Oldfeild was born May 24, 1905, in Kolhar, India. During 1932-46, he was employed by the Indian Radio and Cable Communications Company. In 1947, he became assistant engineer for the Government of India Overseas Communication Service.

Verne Warren Shear (AM '06, M '12, Member for Life), owner and president of Verne W. Shear and Company, died recently. Born December 2, 1880, in Saybrook, Ohio, he graduated from the Case Institute of Technology in 1906 with the B.S. degree in electrical engineering. Mr. Shear was employed by Westinghouse in Pittsburgh, Pa., until he came to Akron, Ohio, in 1912. At that time, the old Northern Ohio Traction and Light Company was engaged in the construction of the Gorge Power Plant. Mr. Shear remained in this construction engineering work for a year and a half. He later went into business as a sales engineer, from which he retired about 5 years ago.

OF CURRENT INTEREST

Radio-Electrocardiograph System for Electrocardiograms While Patients Exercise

AN OFFSHOOT of the United States' successful astronaut program is expected to provide a major breakthrough in the diagnosis of cardiac disorders, it was revealed recently at the 10th Annual Convention of the American College of Cardiology.

Physicians at the meeting saw demonstrations of a new, simplified radio-electrocardiograph system which, for the first time, makes practical the taking of electrocardiograms in doctor's offices or hospitals while patients are exercising.

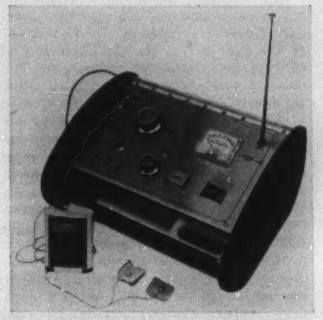
The new instrument, called the RKG *100*, was developed by Telemedics, Inc., of Southampton, Pa., wholly owned subsidiary of Vector Manufacturing Co., Inc. Its predecessor was designed for the extensive physiological testing program which resulted in Commander Alan B. Shepard becoming the nation's first space explorer.

The RKG *100* uses a pocket-size transmitter which broadcasts a patient's heart beats to a receiver, as far as 500 feet away. The receiver relays the information to an oscilloscope, electrocardiogram recording machine, or tape recorder for medical interpretation.

The lack of any connective wiring between the patient and the recording instruments permits freedom of movement prohibited with previous EKG equipment.

The medical significance of this was indicated by Dr. Samuel Bellet, chief of the Division of Cardiology of Philadelphia General Hospital, in a paper titled "The Electrocardiogram During Exercise as Recorded by Radio-Electrocardiography—Preliminary Studies."

On the basis of 270 patients studied, Dr. Bellet stated, "These data indicate that the electrocardiogram taken during exercise is an extremely valuable adjunct in the diagnosis of myocardial abnormality, particularly the presence of coronary artery disease. The information which is obtained during the period of exercise is often unavailable or inadequately shown in the post exercise tracing."



The pocket-size transmitter of the RKG 100 radio-electrocardiograph system broadcasts the patient's heartbeats to the compact receiver located as far as 500 feet away. The receiver relays the information to an oscilloscope, standard EKG recording apparatus, or magnetic tape recorder for analysis.

Collaborating with Dr. Bellet in these clinical evaluations of the RKG *100* were Drs. Stavros Deliyiannis and Marcel Eliakim of Philadelphia General Hospital and Richard Berman and Bernard Schwartz of Telemedics, Inc.

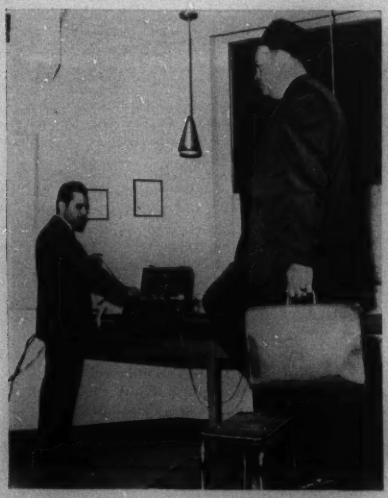
It is anticipated that such information will help to solve the medical mystery of why some apparently healthy patients have suffered cardiac attacks shortly after a standard electrocardiogram had revealed no abnormality.

During such conventional examinations, the patient is normally reclining and the heart is not under stress. The studies by Dr. Bellet indicate that cardiac defects frequently are revealed only while the heart is responding to the stress of exercise.

Of 147 hypertensive or arteriosclerotic patients observed by the Philadelphia cardiologist, 58% showed abnormal responses "only or chiefly during the period of exercise."

Several new applications of electrocardiography are foreseen by physicians because of the flexibility of the radio-electrocardiograph system. Continuous monitoring of many cardiac or recovery room patients at one hospital station is one probability.

Observation of the heart's reaction to stress as a person goes about his daily work also will now be possible in many cases.



Salesman has radio-electrocardiogram taken while simulating the normal exertion of his occupation (*left*) at the Heart Station of Philadelphia General Hospital. Miniaturized transmitter, called RKG *100*, in his shirt pocket broadcasts heart's responses to compact receiver which relays information to standard EKG recorder being read by Dr. Stavros Deliyiannis. (*Right*) Patient's heart response to exercising on bicycle is read. This simplified radio-electrocardiograph system, developed by Telemedics, Inc. of Southampton, Pa., makes practical for the first time the taking of electrocardiograms while patients are exercising.

The RKG *100* apparatus utilizes specially designed, disposable electrodes; a 10-ounce battery-operated radio transmitter, and a portable desk-model receiver.

"The records obtained with this method," commented Dr. Bellet, "show a steady and stable base-line. The tracing is faithfully recorded during various forms of activity. The apparatus is simple; it can easily be applied for use in a doctor's office or in a hospital."

Electrodes are used which consist of a patch-type adhesive bandage with a unique electrode paste reservoir, a metallic screen, and contact snap fastener. They are easily secured on the skin in a manner similar to applying most adhesive bandages and comply with the skin's surface motion.

The FM radio transmitter is 4 inches high, 3 inches wide, and 1 inch thick. Input signals from the electrodes are carried by thin flexible wires to the transmitter where they are amplified and transmitted from an antenna in the transmitter itself.

The transmitter batteries are self-contained and capable of operating continuously up to 5 hours without recharging. They can be recharged simply by placing the complete transmitter in the automatic charging system located on the receiver. Since the system is normally operated during the day, recharging can take place conveniently overnight.

The transmitter operates on an authorized radio frequency allocated by the Federal Communications Commission.

The radio receiver is approximately 12 by 14 inches and 8 inches high. A collapsible antenna extends to a height of 3 feet.

The receiver console contains a selector switch which allows channeling the electrocardiographic signal to any conventional electrocardiographic recording instrument, a cathode-ray oscilloscope, a magnetic tape recorder and playback system, or all three simultaneously.

It also has a skin resistance meter which permits a fast and accurate measurement of total body resistance between the electrodes as a check on proper electrode application.

One-millivolt calibration is provided from the receiver console. This introduces a sharp wave of 1-millivolt amplitude on the recording and oscilloscope instruments. **EE**

New Square Panel Fluorescent Lamp Unveiled

A NEW fluorescent lamp in the shape of a thin, square panel was unveiled recently by the General Electric Company (GE). The company announced that it would begin marketing it immediately.

The lamp, 11⅝ inches square and 1½ inches deep, was classified by D. D. Scarff, general manager of GE's large lamp department, as "one of the most significant product innovations since General Electric introduced the first fluorescent lamp in 1938."

Under development in GE's research and engineering laboratories at Nela Park, Cleveland, Ohio, for more than 3 years, the unique fluorescent lamp adds a square form to the point, linear, and circular light sources which have been available in the past.

Compact and efficient, the panel lamp is designed to fit a module 12 inches square, and offers a practical and convenient way of getting more light in a small space. It can be used singly or in groups, and lends itself to built-in, surface-mounted, suspended, and free-standing applications.

In addition to its small size and high light output, the lamp offers several major advantages to users because of the way in which it was designed, it was pointed out.

Its face plate, attractive both lighted and unlighted, features a waffle-pattern configuration with 1¾-inch squares. These facilitate the use of the lamp in fixtures with louvers of an identical grid spacing for efficient control of the light. The face plate diffuses the light, concealing the path of the arc.

The lamp's bi-pin terminals for electrical connection are positioned behind an outer rim at adjacent corners, and are entirely within the over-all depth and other dimensions of the panel. This arrangement makes for simplicity in applying the lamp to fixtures of various designs. The terminal arrangement also permits the use of push-pull connectors, capable of being inserted with one hand, making lamp installation and maintenance simple and easy.

The lamp will come in two types. The first to be available emits light in equal amounts from the front and back. Another version will have a reflective coating on the back side to direct most of the light from the front.

The lamp is designed to operate at either 80 watts or 50 watts. At 80 watts it produces 4,800 lumens, or units of light, giving it an efficiency of 60 lumens per watt of electricity consumed. This is 10% more light than is emitted by four conventional 20-watt fluorescent lamps. The average brightness of its face is approximately 3,200 foot-lamberts.

At 50 watts the lumen output of the lamp is 2,900 lumens, the efficiency 58 lumens per watt, and the brightness proportional to the lumens. The rated life of the lamp is 7,500 hours at both wattages.

It was pointed out that new fixture concepts and designs are necessary for the

GE's panel fluorescent lamp is examined (*left*). Lighted panel shows the waffle pattern of the face plate of the lamp, which compresses a 5-foot-long arc in a 1-foot-square area. Rated at 80 watts, the lamp emits 10% more light than four conventional 20-watt fluorescent tubes. Prototype of a free-standing fixture (*right*) shows how the lamps may be used to provide more than 1,000 foot-candles of illumination for a work bench or industrial assembly area.

square fluorescent lamp, and that lamp specifications now are being presented to fixture manufacturers.

Mr. Scarff noted that development of the square fluorescent lamp was announced by GE in 1959. Before a commercial version could be introduced, he said, intensive research and development were required involving the lamp's design, the fabrication of its parts, and the creation of new machinery for its construction. All of these called for techniques and equipment completely new to the lamp industry.

Manufacture of the lamp involves molding two individual squares of glass, one serving as a configurated face plate and the other with an open trough which loops six times across the lamp. After processing, the face plate and the piece with the trough are sealed together, compressing a 5-foot-long arc path within a 1-foot-square area.

By molding the glass pieces separately it has been possible to keep the lamp light in weight without sacrificing its strength. **EE**

New Spinning Wheel Weaves Threads to Space

There's a new type of spinning wheel in Lockheed's Van Nuys, Calif., plant weaving money-saving multiwire space-age cables.

The rapid-rotating (up to 60 rpm) 6-foot-diameter wheel is part of a 25-foot-long planetary wire-stranding machine. Its product makes possible the electronic checkout and launching of Lockheed-built satellites and missiles at Vandenberg Air Force Base and Cape Canaveral.

The wire-stranding machine and its accessories, purchased outside but modified with off-the-shelf items by Van Nuys plant engineers, cost Lockheed Missiles and Space Division approximately $15,400. However, savings in the year it has been in operation add up to ten times that figure—$150,000 Lockheed estimates.

To have the cable work done outside the Van Nuys plant, the firm reports, would cost three times as much, and Lockheed would not have retained complete control over production, inspection, and often tight time schedules (sometimes as little as a few hours' notice).

In recognition of the savings—both time and money—a Lockheed Conservation Citation has been awarded for the cabling operation.

So far, some 5 miles of cable (more than 25,000 feet) have been produced by the wire-stranding machine, nicknamed "the sausage maker" by employees.

In the complete operation, individual wires are reeled out from the 18 spools on the face of the big revolving planetary wheel at the rate of from 10 to 48 feet per minute, sent twisting through holes in a smaller spinning wheel (called a "spider"), shaped into a cable by a forming block (¼ to 1⅜ inches, depending on number and size of wires), and finally pulled onto a motor-driven reel at the other end of the machine.

The wires, held together with a plastic tape binder, are then encased in a durable Neoprene-rubber protective jacket, and metal connectors are attached to the cables.

The completed multiwire cables—each of necessity a custom-made job because of the diverse tasks performed—go to Vandenberg and Cape Canaveral where they are used in the electrical transmission of information between blockhouse and launch pad on the readiness of the Polaris missile or Agena satellite components from checkout to lift.

Engineers note that the operation at Van Nuys is not limited to missiles and satellite ground support equipment but is available for numerous other cable requirements throughout Lockheed and the industry. **EE**

TURNING OUT multiwired cables destined for missile and satellite launch pad and blockhouse electronic operations is a new type of spinning wheel at the Van Nuys, Calif., plant of Lockheed Missiles and Space Division. It is part of a 25-foot-long planetary wire-stranding machine which has thus far produced more than 5 miles of cable in the year it has been in operation—much of it on short notice. The money- and time-saving machine cost approximately $15,400 but savings have added up to ten times that figure. Seen checking over one of the 18 wire spools is technician Arthur Harris. Wheel will turn up to 60 rpm.

Recorder Automatically Stamps Time and Date on Tape

A new recorder introduced by the Westrex Company, a division of Litton Industries, can be actuated by the sound of a voice and automatically stamps the time and date on the magnetic tape.

The type *RA-1651* signal-actuated voice recorder was designed for voice communications systems that must maintain a complete and accurate log of messages. Examples are police and fire department communications systems and air traffic control centers. It is expected to be useful in gathering information for police work, such as in around-the-clock surveillance in a number of jail areas.

The unit can operate continuously for 25½ hours without a change of reels if the slowest speed of ⅛ inch per second is chosen. Other tape speeds are also available.

From one to four separate channels of information may be recorded. Because of this, and the long recording time, reloading of tapes, and space required for tape storage are minimized.

Two units can be coupled so that one automatically goes into operation when the tape on the other reaches the end of the reel or breaks. Besides assuring continuous operation, this automatic feature can double the continuous recording time.

The unit begins recording within 10 milliseconds after a voice signal is detected, assuring that no intelligence is lost. A time stamp automatically stamps the time and date at the end of the message. If continuous operation is selected by switch, the time is automatically stamped every minute.

Fast starting time is obtained by running the synchronous tape drive motor continuously, but not moving the tape until a solenoid engages it to the capstan. This capstan is actuated by an incoming audio signal or by a front panel control switch in the continuous mode of operation.

Tape event search can be made by either reproducing the recorded sound or by reading the time and date logged on the magnetic tape. Sound reproduction quality is comparable with that of conventional tape recorders.

The basic recorder comprises three in-

terconnected units that can be mounted in existing radio racks or in an optional cabinet. The three units, all of the standard 19-inch width, are a tape transport unit, a control panel, and a transmission equipment panel containing from two to five plug-in modules depending on the number of channels selected.

The unit is powered by a 115-volt, 50- or 60-cycle current. Ease of operation and maintenance are built into the system. Selection of manual or automatic operation, reproduce, scan, or stop is made from a single panel switch. Lamps indicate that tape has run out, or that the time stamp should be reset because of a power failure. A volume meter and volume level controls are provided for each channel. A jack makes it possible to monitor the recording by headset or loudspeaker.

Magnetic tape capacity is 4,800 feet of ¼-inch-wide 0.7-mil Mylar tape on 10½-inch NAB reels. **EE**

Automatic Landing System Slated for 10 Navy Carriers

An automatic landing system that permits flight operations under adverse weather conditions will be installed aboard 10 U. S. Navy carriers, Bell Aerosystems Company announced recently.

Under contract with the U.S. Navy Bureau of Ships, Bell—a Textron company—is producing 12 automatic landing systems. In addition to the 10 carrier installations, 2 systems will be employed as land-based training devices.

The automatic landing system (ALS) was developed under contract with the Navy's Bureau of Ships by Bell's Avionics Division which will also produce the 12 units.

The first carrier-based system is planned for installation aboard the nuclear powered *U.S.S. Enterprise*. Following evaluation, delivery of the remaining carrier units will begin in late 1962 and continue through 1964.

In addition to the *U.S.S. Enterprise*, the Bell landing system— officially designed the *AN/SPN 10*—will be installed on the *Constellation, Kitty Hawk, Independence, Ranger, Saratoga, Forrestal, Roosevelt, Coral Sea,* and *Midway*.

The automatic landing system will improve aircraft operations during fog and other unfavorable weather conditions. Installed aboard a carrier, the Bell system electronically guides an approaching aircraft to "touchdown" on the carrier deck without the pilot being required to touch pitch and bank controls or to make visual contact with the carrier.

The Bell system assumes control of an aircraft when it is several miles from the carrier. Precision radar tracks the airplane and relays its position to a computer. The computer compares the aircraft's position with that of the carrier and generates control commands which are radioed to the aircraft's automatic pilot. The automatic pilot, in turn, controls the aircraft, holding it on a proper flight path.

As the aircraft approaches the carrier deck, the landing system will automatically give the pilot a "wave-off" signal if his airplane is not exactly aligned for safe landing. In the event of a wave-off, the aircraft is flown around the landing pattern for another attempt.

While developing its landing system, Bell performed more than 3,000 automatic landings on carriers and airfields. Bell has also developed a land-based system, the *AN/GSN 5*, which has been turned over to the Federal Aviation Agency for commercial evaluation. **EE**

Pulsed Neutron Generator Will Be Installed at JAERI

A pulsed neutron generator has been completed by the Matsuda Research Laboratory of the Tokyo Shibaura Company, Ltd., and will be installed at the Japan Atomic Energy Research Institute (JAERI) near Mitco City, in conjunction with a semihomogeneous critical assembly unit known as a zero-power atomic reactor.

This combination, developed in Japan, may be used for research or development purposes.

The neutron generator produces high-speed neutrons by application of accelerated deuterium to tritium target, by means of nuclear fusion.

The newly completed Toshiba unit is capable of adjusting the duration time freely, and the generating neutron as well, either continuously or in pulsed conditions.

The capability of this Toshiba instrument ranges from 10 to 100 billion neutrons, comparable to that of a unit of a small-power reactor.

It is, in addition, able to manufacture pulsed neutrons at a far lower price than an orthodox atomic reactor.

Compared with the radium-beryllium natural neutron source, its cost is estimated as constituting 0.001% of its entire ray source.

This new equipment generates neutrons having a high-energy output of 14 million electron volts.

It does not bring about any gamma ray condition, which would be inevitable if an atomic reactor were to be employed or if a radium-beryllium ray source were resorted to.

The generator also can produce thermo-neutron flux, as atomic reactors do, when the target is wrapped securely by means of such moderators as paraffin, yet not encounter any difficulty which might arise from waste.

Applications of the new unit include neutron experiments, activation analysis, production of short-life-type isotopes, biological irradiation experiments, etc.

Toshiba previously built a neutron generator for the Science Department of Tokyo University. **EE**

Optical Radar Could Map Moon from Earth Base

A "light-beam" radar for many scientific explorations, including mapping the moon more accurately than before, has been developed by Hughes Aircraft Company as a research companion to its new "Colidar" spacecraft radar, a company scientist disclosed recently.

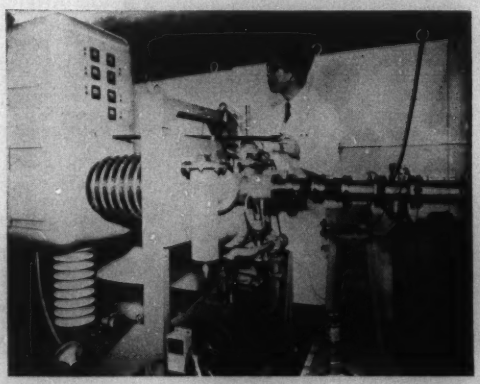
Eventually, an optical radar operating from earth could spotlight its beam on a moon area only 10 miles in diameter, Dr. G. F. Smith, of Hughes research laboratories, Malibu, Calif., said.

"This would make possible sharper pictures (even determining more accurately the height of moon mountains) than those now made by 'illuminating' the moon with radio or microwave signals from ordinary radar which disperses its beams over such large areas that their intensity is dissipated," he declared.

"The compact, lightweight device has exceptionally high angular resolution and, although it is still in early stages of development, already produces a narrow beam 100 times as narrow as the signal from conventional radar," he added.

The key part of the radar is its light source, a "laser" (for Light Amplification by Stimulated Emission of Radiation), invented last July by Dr. T. H. Maiman of Hughes, which produces an intense burst of pure red light in an extremely narrow beam.

In recent experiments, the beam-width of the Hughes optical radar system was 0.023 degree. Lasers should eventually provide beams as narrow as 0.004 degree with-



A PULSED neutron generator, recently completed by the Matsuda Research Laboratory of the Tokyo Shibaura Electric Company, Ltd., will soon be installed at JAERI, the Japan Atomic Energy Research Institute near Mito City in Ibaragi Prefecture, in conjunction with a semihomogeneous critical assembly unit which is known as a zero-power atomic reactor.

out the aid of lenses. The laser that was used, however, gave an 0.7-degree beam which was further reduced to 0.023 degree by a telescope with a 6-inch mirror. Present-day ruby lasers do not produce theoretically expected beam-widths due to imperfections in the ruby crystals.

The laser transmitter operated with peak powers up to 2,000 watts at a wavelength of 6,943 Angstroms (0.00006943 cm). For most of the experiments, each output burst consisted of many closely spaced microsecond pulses over a period of about 1 millisecond. The shape of the output burst was substantially improved, however, by cooling the ruby to about —150 F, in accordance with a technique recently demonstrated by R. J. Collins of the Bell Telephone Laboratories.

Three types of noise affect the system: internal or receiver noise, external noise due to undesired light which enters the receiver through the red filter, and fluctuation or "shot" noise in the signal itself.

The receiver noise is due to dark current in the phototube. Refrigeration can reduce this if necessary.

For daytime operation on the surface of the earth, that part of the scattered sunlight which can pass through the red filter limits the performance of the system. Use of a red filter with a narrower spectral bandwidth can reduce noise. The experimental receiver made use of a 15-Angstrom interference-type filter. A 1-Angstrom filter would improve the signal-to-noise ratio by 15 times. Appreciable further improvement will have to await the development of exotic receiving techniques such as optical heterodyning or laser preamplification.

The fluctuation noise provides an ultimate limitation for a laser radar if the other two sources of noise can be eliminated. This noise is fundamental in nature and is due to the random rate of arrival of light photons which make up the received signal. **EE**

First Deep-Space Television Described

The first method for receiving television from deep-space vehicles probing Mars and beyond was described recently at the National Symposium on Global Communication.

Sperry Gyroscope Company engineers explained details of a system that can receive television and other broadband telemetered information 400 times faster, more efficiently, and at one third the cost of the most advanced methods known today.

Present ground-based antennas are limited to reception of five picture "frames" per minute. The Sperry system can accept, process, and present 30 frames per second, the speed of normal continuous motion such as that seen on a home television set.

The new system opens the way to advances in space communication, navigation, and exploration hundreds of millions of miles from earth, thought by scientists to be years away. It has been demonstrated successfully in a working model at the company's Great Neck, N. Y., headquarters.

Reversing a trend which presently favors single antennas as large as three football fields, a unique array of smaller antennas, each approximately 100 feet wide, has been designed. These will be more efficient than a larger dish (70 db), engineers explained, but will not be affected by mechanical tolerance problems or atmospheric signal distortions inherent in the vast expanse of one huge reflector.

Called Automatic Three-Dimensional Electronic Scanned Array (ATHESA), the system groups its antennas in a circular pattern and operates them at identical power and frequency to duplicate electronically one giant dish.

The relatively small size of each antenna in the ATHESA array minimizes both atmospheric distortion and mechanical tolerance problems. Antennas can be added to boost the gain of the ATHESA with no increase in signal distortion.

Signals from a space satellite-borne transmitter are received at each antenna in the ATHESA and automatically processed through circuits called phase-locked loops to correct for atmospheric and mechanical errors. A reference phase is established for each antenna loop and the phase of each received signal adjusted to coincide with the reference phase. The signals then are combined in a common receiver. This technique, known as phase coherence, assures maximum detection and amplification of the energy transmitted from space, the engineers said.

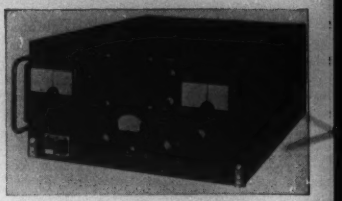
Until now, gigantic antennas had been believed necessary to receive information from small transmitters in weight-limited space vehicles. But Sperry scientists say that most steerable antennas over 200 feet in diameter are both ineffective and too costly. Some antenna installations have been estimated at well over $100 million. **EE**

Radio Receiver Can Pinpoint Astronaut's Landing Location

A radio receiver which can pinpoint the spot where an astronaut has landed in a space capsule after orbiting the earth has been developed by International Telephone and Telegraph Corporation (ITT).

The receiver is used by patrol aircraft to pick up signals from a radio transmitter located in the space capsule. The received signals are displayed as a spot of light on the face of a small "picture tube" on the receiver. The position of the light on the tube face indicates whether the patrol aircraft is on course and enables the pilot to "home in" on the signal.

The equipment was developed by the ITT Kellogg Space Communications Laboratory, Fort Wayne, Ind., a part of the ITT Kellogg Space Communications Systems Division, Chicago, Ill.



A RADIO RECEIVER which can pinpoint the spot where an astronaut has landed in a space capsule after orbiting the earth has been developed by ITT.

The radio receiver is designed to receive various types of signals known technically as continuous wave (CW) signals, single-pulse signals, and correlated double pulses. This versatility makes the equipment more reliable and results in greater safety for the astronaut. If one type of signal reception becomes inoperative, another may be used to locate the capsule. **EE**

Sound Waves Amplified By Phonon Maser Effect

The direct amplification of sound waves using microwave radio energy as a power source has been demonstrated for the first time, by Dr. E. B. Tucker of the General Electric Research Laboratory. Amplification of the sound waves—called phonons—is accomplished by "stimulated emission" of energy by atoms as they change from a higher to a lower energy level. This is the same mechanism used in the maser (microwave amplification by stimulated emission of radiation) to amplify electromagnetic radiation, and the new phenomenon has been termed the phonon maser effect.

According to Dr. Guy Suits, General Electric vice-president and director of research, this is the first time that stimulated emission has been successfully used to amplify energy other than electromagnetic energy. Dr. Suits noted that although no immediate commercial application of the phenomenon is in sight, it provides a significant extension of the principle of stimulated emission, and represents an advance in understanding of the physics of the solid state. The technique may also provide a valuable research tool permitting experimental study of the role of phonons in many physical phenomena. For example, it may make possible an acoustic oscillator for generating sound waves of higher frequency than are now attainable.

In both the maser and the new phonon maser effect, individual atoms are raised to a high energy state by irradiating—or "pumping"—them with high-frequency electromagnetic energy. Then, when signal energy of a lower frequency is introduced, stimulated emission of the signal frequency occurs. Under the proper conditions, the stimulated emission may be strong enough to produce amplification

CORRECTION: In "Letters to the Editor" department of the May 1961 issue, p. 398, the last section of the first paragraph of the letter entitled "Thermonuclear Power" should read as follows: "Thus, the blocking effect of the magnetic field on the flow of ions to the surrounding cylindrical wall is completely eliminated by the self-induced radial electric field which automatically sets itself perpendicular to the magnetic field. The fabulous magnetic bottle may be merely a fantastic dream."

Dr. E. B. Tucker inserts ruby rod into the apparatus used to measure interaction between sound waves and electromagnetic radiation. "Phonon maser effect," first observed by Dr. Tucker at the General Electric Research Laboratory, permits sound waves to be amplified in a way analagous to amplification of electromagnetic radiation by masers.

of the signal. In the maser, the pump, signal, and output are all electromagnetic energy, whereas in the phonon maser effect only the pump is electromagnetic energy—the signal and output are both mechanical, or sound, energy.

The effect has been demonstrated with short pulses of very high frequency (9.3 kmc) sound in a ruby crystal. Ruby consists of alumina (Al_2O_3) with chromium ions as an impurity. When it is subjected to a magnetic field, the electrons on the chromium ions, acting as small magnets, tend to line up with the field. Each electron has four characteristic energy levels, corresponding to how closely it lines up with the applied field. Most of the electrons are in the lowest energy level, but can move to higher energy levels by absorbing energy at a certain resonant frequency, which is set by the magnetic field strength and the characteristics of the electrons in the crystal. The reverse transition, from a high to a low energy level, can be made by emission of energy at the resonant frequency.

There is also interaction between the vibrations of the atoms in the crystal lattice and the energy states of the electrons, due to the electric fields of the atoms in the lattice. As the atoms vibrate, the electric fields acting on the electrons vary and this affects their energy levels. This interaction is what makes the phonon maser possible, and Dr. Tucker's work permits it to be observed directly and measured accurately for the first time. Dr. Tucker first reported his measurements in *Physical Review Letters* for February 15, 1961, and his first report on phonon amplification appears in the May 15 issue.

To achieve amplification by the phonon maser effect, as in the conventional maser, most of the electrons are raised two energy levels above the lowest by pumping with electromagnetic energy at a frequency which causes this transition (23 kmc in this case). Then, when energy at a lower frequency is introduced, stimulated emission occurs.

The phonon amplification observed by Dr. Tucker is about 12% per centimeter of ruby. This is probably enough to overcome losses from crystal imperfections and deviations of the ends of the crystal from perfect flatness and parallelism. To achieve high amplification, the waves must be reflected back and forth through the crystal many times, being amplified a little each time. The ends must be flat and parallel, or the waves reflect unevenly and interfere with each other. The ruby crystal is kept at a temperature of about 1.5 above absolute zero to minimize the effects of thermal vibrations. **EE**

Radio-Radar Telescope Will Probe Solar System

The radio-radar telescope with the largest reflector in the world—1,000 feet in diameter—will be ready to probe the far reaches of the solar system by next February, it was announced by the Cornell University scientists who designed and are supervising its construction near Arecibo, Puerto Rico.

The Department of Defense Ionospheric Research Facility will make it possible to study the upper atmosphere, the composition of space and the solar system by radar methods, as well as to send and receive radio signals to and from deep within the universe.

The excavation for the giant radar dish has already been dug and the concrete and steel pylons that will support the feeder system are under construction. A permanent, almost 2-mile-long service road around the rim of the excavation has been completed.

When the pylons are finished, two of them will be 265 feet in height and the third will be 390 feet high—to make up for differences in elevation in the surrounding terrain.

The bases of the pylons will be octagonal in shape and will measure 36 feet in diameter for the large tower and 25 feet for the small ones. The pylons—cross shaped in cross section—measures 26 feet in diameter where they rest on bases.

Five 3¼-inch cables from the top of each pylon will radiate outward and be connected to anchor stays. The cables support the triangular steel structure 216 feet on the side which supports the 304-foot feed arm. This arm carries the 96-foot line feed.

The reflector mesh will be supported by a cable network with frequent supports and tie-downs to maintain the required shape tolerance of ± 0.1 foot from an exactly spherical surface.

Radio signals will be picked up by a line feed movable on a theoretical paraxial surface 435 feet in radius and extending to a maximum angle of 20 degrees each side of the zenith.

The estimated costs are $4.1 million for the reflector and feed system, with the over-all project cost at about $6.5 million, much less than similar sending and receiving installations because the Cornell designers are placing the reflector in a natural bowl for economical construction and because the reflector is stationary. The telescope is pointed by rotating and translating the line feed.

The general conception of the Arecibo observatory project, the selection of the site, and development of the criteria, are the work of Prof. W. E. Gordon, project officer for Cornell University. Philipp Blacksmith of the Air Force Cambridge Research Center is project officer for that organization, which is monitoring the design and construction in behalf of the funding organization, the Advanced Research Projects Agency (ARPA).

The engineering design and supervision is by a joint venture consisting of Von Seb. Inc., Developmental Engineering Corp., Severud-Elstad-Krueger Associates, and Praeger-Kavanagh, with T. C. Kavanagh of the latter organization acting as chief engineer.

The design of the 96-foot line feed was by Technical Research Group, Inc., and is based on a principle worked out by the Cambridge Research Center. Access roads and buildings associated with the telescope are being constructed by the U. S. Army Corps of Engineers. **EE**

The excavation for what will be the world's largest radio-radar telescope reflector dwarfs the service road cut in adjacent mountainsides. The reflector site is almost a fifth of a mile wide. The natural bowl was selected because soil near Arecibo, Puerto Rico, is porous. The radio-radar telescope, designed by Cornell University scientists, will be called the Department of Defense Ionospheric Research Facility.

Future Meetings of Other Societies

NSPE, 27th Annual Meeting, July 4-7, Olympic Hotel, Seattle, Wash. K. E. Trombley, National Society of Professional Engineers, 2029 K St., N. W., Washington 6, D. C.

Summer Study Course in Nonlinear System Analysis, July 10-21, Case Institute of Technology, Herbert Schultz, Manager of Special Programs, Same, University Circle, Cleveland 6, Ohio.

Western Plant Maintenance & Engineering Show, July 18-20, Pan Pacific Auditorium, Los Angeles, Calif. Same, Western Office, 79 Monadnock Bldg., San Francisco 5, Calif.

Northwest Computing Association, Annual Conference, July 21-22, Vancouver, B. C., Canada. Conference Information, NCA, Box 836, Seahurst, Wash.

American Astronautical Society, 4th Western Regional Meeting, August 1-3, Sheraton-Palace Hotel, San Francisco, Calif. S. B. Kramer, Lockheed Missiles & Space Div., Sunnyvale, Calif.

18th Annual Congress of Pure and Applied Chemistry, August 6-12, Montreal, Que., Canada. Chairman, Central Committee, Same, National Research Council, Ottawa, Ont., Canada.

1962 Conference on Standards and Electronic Measurements, August 14-16, National Bureau of Standards Laboratories, Boulder, Colo. Dr. J. M. Richardson, Chief, Radio Standards Lab., NBS, Boulder, Colo.

2nd International Electronic Circuit Packaging Symposium, August 16-18, University of Colorado, Boulder, Colo. Bureau of Continuation Education, Univ. of Colorado, Boulder, Colo.

5th International Conference on Coordination Chemistry, Aug. 21-Sept. 1, Wayne State University, Detroit, Mich. Prof. S. Kirschner, Chemistry Dept., Wayne State University, Detroit 2, Mich.

Western Electronic Show & Convention, Aug. 22-25, Cow Palace, San Francisco, Calif. Don Larson, WESCON Mgr., 1435 La Cienega Blvd., Los Angeles 35, Calif.

International Heat Transfer Conference, Aug. 28-Sept. 1, University of Colorado, Boulder, Colo. L. S. Dennegar, Dir. of Pub. Rel., American Society of Mechanical Engineers, 29 W. 39th St., New York 18, N. Y.

Overseas

United Nations Conference on New Sources of Energy, Aug. 21-31, Rome, Italy, A. G. Katzin, Executive Secretary, United Nations Conference on New Sources of Energy, United Nations, New York, N.Y.

Rassegna Internazionale Elettronica, Industrial and Commercial Exhibit, Aug. 21-31. Via della Scrofa 15, Rome (Organized by "Rassegna"—not United Nations or the Italian Government). Same.

Third International Conference on Analog Computation, Sept. 4-9, Belgrade, Yugoslavia. Yugoslavia Committee for ETAN, Terazije 23/VII, Belgrade, Yugoslavia.

Convention on Impact of Nuclear Development on Electricity Supply and Instrument Techniques, Sept., London, England. Institution of Electrical Engineers, Savoy Place, London W. C. 2, England.

NEW BOOKS

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ANALOGUE COMPUTATION, VOLUMES 1, 2, 3, 4. By Stanley Fifer. McGraw-Hill Book Company, Inc., 330 W. 42nd St., New York 36, N. Y., 1961. 4 volumes, 6 by 9¼ inches, bound. $39.50. This 4-volume work has continuous page and chapter numbering, with the table of contents in Volume 1 only, and indexes in Volume 4 only. It is intended for the embryonic and the practicing mathematician, physicist, or engineer. Volumes 1 and 2 are devoted primarily to the general-purpose d-c functional computer, the principal element of which is the direct-coupled feedback amplifier, and they form a basic course in analog computation. The term "functional computer" denotes that each of its components performs one or more distinct mathematical operations. This is in contrast to the "direct analog computer" described in volumes 3-4 (intended for an advanced course), in which there is generally a one-to-one correspondence between the parameters and the variables of the given system and those of the computer mechanization.

ANNUAL REVIEW IN AUTOMATIC PROGRAMMING, VOLUME 1. Edited by Richard Goodman. Pergamon Press, 122 E. 55th St., New York 22, N. Y., 1960. 300 pages, 6¼ by 9¾ inches, bound. $10. This first volume of a proposed series of annual reviews contains the 18 papers presented at the Conference on Automatic Programming of Digital Computers held at Brighton Technical College (England) in April 1959. Most of the papers have been modified to deal with points made in discussion. Constituting a review of work being done in this field, particularly in Britain, the papers discuss such topics as future trends, autocades, interpretative and translating programs, special automatic programming systems, and the philosophy of programming. Also included are the two pioneer papers on computable numbers by Dr. A. M. Turing, enunciating the fundamental theory on which automatic programming is based.

ADAPTIVE CONTROL SYSTEMS. Edited by Eli Mishkin and Ludwig Braun, Jr. McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1961. 533 pages, 6¼ by 9¼ inches, bound. $16.50. This book is an outgrowth of an extension course for industry prepared by the Electrical Engineering Department of the Polytechnic Institute of Brooklyn. The intent is to report broadly on recent advances in the general area of feedback control systems, with special emphasis on adaptive control systems. The first chapter defines and describes the concept and development of adaptive control systems. The remaining chapters are individually authored monographs organized in groups which deal with four aspects of the theory and design of feedback control systems: linear systems, nonlinear systems, adaptive control systems, and some selected topics in systems engineering (digital technique, analysis of competitive situations, decision theory, analysis of queueing systems, and multistage processes).

BASIC PRINCIPLES OF FISSION REACTORS. Interscience Publishers, Inc., 250 Fifth Ave., New York 1, N. Y., 1961. 314 pages, 6¼ by 9¼ inches, bound. $7.50. This introduction to basic principles assumes a background of physics, mathematics, and chemistry, but none in nuclear technology, and employs a mathematical approach. The first two chapters introduce important ideas in nuclear engineering in preparation for the following chapter's discussion of a nuclear power station. Succeeding chapters contain a detailed and quantitative discussion of the nuclear reactor itself, its various types and structural and operative aspects, stopping short of detailed design considerations. Attendant subjects such as radiation protection, health physics, waste disposal, and economic considerations are briefly discussed to place the reactor in proper perspective.

BERECHNUNG ELEKTRISCHER MASCHINEN. By W. Schuisky. Springer-Verlag, Vienna, Austria, 1960. 534 pages, 6¾ by 9¾ inches, bound. $26.20. In contrast with the various modes of operation, the calculation of different electric machines has much in common. It has therefore been possible to summarize in this book the underlying principles of calculation of electric machinery. Due to the growing importance of magnetic materials and their application, this area has been given considerable space. The same can be said of the treatment of transients. The calculation of losses has been dealt with in detail, and there are chapters on heating, on the mechanical forces, and on the dimensioning of machines.

BRITISH NUCLEAR POWER STATIONS. By Rolt Hammond. Macdonald and Company (Publishers) Ltd., London, England, 1961. 182 pages, 5½ by 8¾ inches, bound. 25s. In the first three chapters the author outlines the British Nuclear Power program for the next 20 years, and presents a general discussion of the design of nuclear power stations and the special problems of nuclear power. The remaining chapters give the stories of specific British nuclear power stations—Calder Hill, Hinkley Point, Berkeley, and Hunterston; discuss electrical control and switchgear, and give accounts of research in thermonuclear power, and with the Dounreay Sphere. Coordination of nuclear and conventional power plants to meet the fuel shortage expected about 1970 is also discussed.

COMPLEX VARIABLES AND THE LAPLACE TRANSFORM FOR ENGINEERS. By W. R. LePage. McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1961. 475 pages, 6¼ by 9¼ inches, bound. $12.50. This graduate-level text has been written by the Chairman of the Department of Electrical Engineering of Syracuse University to provide an understanding of the theory of Fourier and Laplace transforms, and of the basic theory of functions of a complex variable. No prior knowledge other than a good grounding in calculus is necessary. The text is divided roughly in two parts: Chapters 1 through 8 deal with functions of a complex variable, and 9 through 16 with the Fourier and Laplace transform theories. Separate chapters are devoted to such topics as conformal mapping, integration, infinite series, multivalued functions, real integrals, convolution theorems, impulse and periodical functions, and the *Z* transform. The treatment progresses gradually from an elementary level to a relatively high degree of sophistication.

ELECTRO-EROSION MACHINING OF METALS. By A. L. Livshits. Butterworths, Inc., 7235 Wisconsin Ave., Washington 14, D. C., 1960. 115 pages, 5¾ by 8¾ inches, bound. $5.75. This is a translation of a 1957 Russian work describing the state of the art of electrical machining of metals. Emphasis is given the electropulse method, and other then-new developments. Ways of improving electro-erosion machines are described and possible further developments of electromachining of metals are reviewed. After a general introduction, the five chapters discuss the physical conditions for cutting by the electro-erosion process, the generation of current pulses, automatic control and electrotechnological characteristics of the process, and machine tools for dimensional electro-erosion machining.

ELECTROMAGNETIC STRUCTURE OF NUCLEONS. By S. D. Drell and F. Zachariasen. Oxford University Press, 417 Fifth Ave., New York 16, N. Y., 1961. 111 pages, 5½ by 8½ inches, paper. $2. This monograph provides a critical review and analysis of recent studies of the electromagnetic structure of nucleons. The first chapter is devoted to a precise definition of what is meant by the electromagnetic form factors. The various experiments which have given information on form factors are discussed in Chapter 2, emphasizing theoretical assumptions and approximations made in analyzing the experimental numbers in terms of form factors. Chapter 3 is devoted to the recent dispersion theoretic analyses of the form factors. In

Chapter 4 the validity of quantum electrodynamics is discussed, and it is shown how possible deviations in this theory alter the nucleon form factor analyses.

ELEKTROTHERMIE. Edited by M. Pirani. Second edition. Springer-Verlag, Berlin, Germany, 1960. 451 pages, 6½ by 9¼ inches, bound. DM 61.50. This book consists of papers of 10 authors dealing with the electrical production and engineering applications of high temperatures, mostly over 1,000 C. The manufacture of steel, aluminum, copper molybdenum, tungsten, as well as that of the semiconductors—germanium, silicon, graphite, etc., is discussed. Other topics covered are refining of hydrocarbons, the mass production of spare parts from pressed and sintered powders, the design and construction of electric furnaces. The last chapter discusses new laboratory methods for the research engineer.

ESSENTIALS OF DIELECTROMAGNETIC ENGINEERING. By H. M. Schlicke. John Wiley and Sons, Inc., 440 Fourth Ave., New York 16, N. Y., 1961. 242 pages, 6 by 9¼ inches, bound. $9.50. This book is written for the inquisitive electronic engineer and the advanced engineering student looking for facts about the possibilities and limits inherent in magnetically soft ferrites and high-permittivity dielectrics. Chapter I examines relations in electric, magnetic, and electromagnetic fields in materials with large but constant material parameters—a theoretical investigation and review of idealized dielectromagnetics. Chapter II discusses underlying physical principles, and then describes the frequency, amplitude, and temperature dependencies of ferrites and high-permittivity dielectrics, thus demonstrating how much actual dielectromagnetic ceramics deviate from the simplifying assumptions made in the first chapter. The last three chapters are concerned with application principles of dielectromagnetics—lumped reactive circuit elements in conventional and unconventional uses; elimination and utilization of macroscopic electromagnetic resonance phenomena; and selected classes of unique applications such as nonlinearity, nonreciprocity, and utilization of losses.

FLUORESCENT LIGHTING MANUAL. By C. L. Amick. Third edition. McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1960. 400 pages, 6¼ by 9¼ inches, bound. $12.50. This new edition of the Manual attempts to indicate all the significant advances in fluorescent lamps, auxiliaries, applications, and performance in service since the second edition was published in 1947. The principal original purpose of the manual has been retained: to provide a ready and practical reference source giving the various types of information needed to design, sell, install, and service fluorescent lighting systems.

DER FREILEITUNGSBAU. By Hermann Rieger. Springer-Verlag, Berlin, Germany, 1960. 312 pages, 6½ by 9¼ inches, bound. DM 45. A comprehensive, practical book on the engineering of high-voltage, overhead transmission lines. The entire field is covered: surveying and planning, materials for cables, insulators and other accessories, grounding, tower design, foundations, and the complete erection process. Though based largely on German standards, some reference is made to standards and practices of other countries.

FUNDAMENTALS OF ELECTRICITY. By C. C. Bishop. Chilton Company—Book Division, Philadelphia 39, Pa., 1960. 230 pages, 6¼ by 9½ inches, bound. $6.95. Based on review courses for industrial personnel conducted by the author over a period of 11 years, this book opens with a brief review of the work of those early investigators in the field whose names have been preserved in the nomenclature, the particle theory of electricity, and early ideas of the atom. Methods of generating electricity are then described, with practical design formulas and worked illustrative problems included. The discussion then deals with a-c and d-c theory and apparatus. One chapter is devoted to conduction through liquids, and the material on electronics includes such topics as electron mechanics, current flow by electron emission, tubes, rectification, amplification, X rays, oscillators, wave-shaping devices, phase inverter and junction transistors.

LEHRBUCH DER HOCHFREQUENZTECHNIK, Volume I. By Fritz Vilbig. Fifth edition. Akademische Verlagsgesellschaft Geest und Portig K.-G., Leipzig, Germany, 1960. 949 pages, 6¼ by 9¼ inches, bound. DM 48. This first volume of a comprehensive treatise on high-frequency technique, begins with a presentation of fundamentals—resistors and insulators, capacity, inductance, etc.—and follows with a discussion of the electrical processes in quasi-stationary circuits. There are chapters on wave propagation, on antennas, and on radio interference. The final section deals with hot cathode tubes and with their practical installation. There is an extensive subject index.

MAGNETIC MATERIALS IN THE ELECTRICAL INDUSTRY. By P. R. Bardell. Second edition. Macdonald and Co. (Publishers) Ltd., London, England, 1960. 320 pages, 5¾ by 8¾ inches, bound. 32s 6d. Intended to bridge the gap between an academic study of the properties of magnetic materials and the limited treatment of the subject possible in most textbooks for engineers, and to link the properties of materials with their applications, this book will be helpful to senior students in physics and electrical engineering, and to physicists and engineers in industry. Following explanations of magnetic terminology and units, and a discussion of the influence of magnetic theory on the development of materials, the author discusses the historical development, application and testing of permanent magnets and of soft magnetic materials, and describes special devices such as sound-recorders, nondestructive testers, transductors, and transducers. Selection of new material for this edition has been made to indicate salient trends rather than attempting to catalog the tremendous recent advances in both theory and practice.

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ENGINEERING Societies Library books, except bibliographies, handbooks, and other reference publications, may be borrowed by mail by AIEE members for a small handling charge. The Library also prepares bibliographies, maintains search and translation services, and can supply a photoprint or a microfilm copy of any item in its collection. Address inquiries to R. H. Phelps, Director, Engineering Societies Library, 29 W. 39 St., New York 18, N. Y.

MATERIALS FOR NUCLEAR ENGINEERS. Edited by A. B. McIntosh and T. J. Heal. Interscience Publishers, Inc., 250 Fifth Ave., New York 1, N. Y., 1960. 373 pages, 5½ by 8¾ inches, bound. $11.85. The introductory chapter discusses the use by nuclear engineers of data on the properties of materials. Succeeding chapters concentrate on the behavior and properties of uranium, thorium, plutonium, ceramic fuels, graphite, magnesium, beryllium and zirconium. The authors of the individual chapters are members of the staff of the United Kingdom Atomic Energy Authority, primarily concerned with the study and selection of materials. A standard framework has been adopted for the individual chapters, with some minor variations. The aim of the book is to provide the best available data and a sufficient discussion of the theoretical background to enable the reader to get a feel for the characteristics of the materials and a knowledge of the extent to which interpolation and extrapolation can sensibly be used to avoid further research and development studies.

MATHEMATICAL HANDBOOK FOR SCIENTISTS AND ENGINEERS. By G. A. Korn and T. M. Korn. McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1961. 943 pages, 6¼ by 9¼ inches, bound. $20. This is a comprehensive reference collection of mathematical definitions, theorems, and formulas for scientists, engineers and students, including both undergraduate and graduate level material. Proofs are omitted, and related formulas are presented in concise tables, enabling treatment and a special arrangement of topics. This special arrangement, within each chapter, is such that a terse, connected review of each subject is accomplished. Numerous references also are given to provide access to other material for more detailed studies. Six appendixes contain numerical tables, tables of integrals and Fourier expansions, and other such useful data.

MODERN PHYSICS FOR THE ENGINEER. Edited by L. N. Ridenour and W. A. Nierenberg. McGraw-Hill Book Co., Inc., 330 West 42nd St., New York 36, N. Y., 1961. 383 pages, 6¼ by 9¼ inches, bound. $9.50. Volume 2 in the University of California Engineering Extension Series designed to give engineers a brief account of recent developments in physics, this book contains 15 lectures given during the academic year 1957-58 at various institutions in California. The lectures have been arranged into three topical sections. Part 1, "The Laws of Nature," contains eight lectures dealing with new particles, nuclear shell structures, electron scattering, electrons and nuclei in ideal crystals, liquid helium, superconductivity, and magnetohydrodynamic waves. Part 2, "Man's Physical Environment," presents three lectures discussing the origin of nuclear species by means of nuclear reactions in stars, radio astronomy, and the origin of the earth's magnetic field. The four lectures in the final part of the book, "Technology," examine controlled thermonuclear fusion, nuclear reactors, particles accelerators, and the frontiers of aerodynamic research.

MODERN MATHEMATICS FOR THE ENGINEER. Edited by E. F. Beckenbach. McGraw-Hill Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1961. 456 pages, 6¼ by 9¼ inches, bound. $9.50. Volume two in the University of California Engineering Extension Series designed to give engineers a brief account of recent developments in mathematics, this book contains 16 lectures given during the academic year 1958-59 at various institutions in California. They have been arranged into three topical groups. Part 1, "Mathematical Methods," contains five lectures dealing with Delta functions, distributions, operational methods for separable differential equations, integral transforms, semigroup methods in the theory of partial differential equations, and asymptotic formulas and series. Part 2. "Statistical and Scheduling Studies," presents five lectures discussing chance processes and fluctuations, information theory, the mathematical theory of control processes, formulating and solving linear programs, and the mathematical theory of inventory processes. The six lectures in the final section of the book, "Physical Phenomena," examine Monte Carlo calculations, difference and functional equations in transmission line theory, characteristic-value problems in hydrodynamics, partial differential equations in fluid mechanics, the numerical solution of elliptic and parabolic partial differential equations, and circle, sphere and other classical problems.

LA MODULATION DE FREQUENCE. By Jean Marcus. Editions Eyrolles, Paris, France, 1960. 317 pages, 6½ by 9¾ inches, bound. NF 43.65. This is a study of the theory of frequency modulation, and a guide to practical applications, useful (if one reads French) to instructors, practicing and student engineers, and technicians, concerned with radioelectricity. Beginning with a discussion of fundamental principles, the author then deals with the production and detection of frequency-modulated waves. He then discusses noise, and the problems of multiple-message point-to-point communication. The final chapters describe examples of proposed future industrial applications.

PHYSICS OF SEMICONDUCTORS. By A. F. Ioffe. Academic Press, Inc., 111 Fifth Ave., New York 3, N. Y., 1960. 436 pages, 6¼ by 9¼ inches, bound. $12.50. This is a translation of the 1957 Russian work by the Director of the Institute of Semiconductors (USSR). Its theoretical base was provided by the quantum theory of solids in the form adopted in the theory of metals by Sommerfeld, Bloch, and Peierls. The study deals with relevant aspects of solid electrolytes and metals first, and then gives a general survey of electronic semiconductors. Then the fundamentals of the quantum theory of semiconductors are described,

followed by chapters on physical phenomena in semiconductors, and methods of measuring their scale basic properties. The final chapter is a survey of the various semiconducting materials, their classification, and study of their particular qualifications.

THE RADIO AMATEUR'S HANDBOOK, 1961. 38th Edition. The American Radio Relay League, West Hartford 7, Conn., 1961. Various pagings, 6½ by 9½ inches, paper, $3.50. This annually revised handbook by and for amateurs treats radio problems in terms of how to do it rather than by abstract discussion. Its objective is to present the soundest and best aspects of current practice rather than the merely new and novel. It is a compendium of technical and trade information useful to all concerned with radio and its applications.

TIME-HARMONIC ELECTROMAGNETIC FIELDS. By R. F. Harrington. McGraw-Hill Book Co., Inc., 330 W. 42nd St., New York 36, N. Y., 1961. 480 pages, 6¼ by 9¼ inches, bound, $13.50. Written as a graduate-level text, the main purpose of this book is to present mathematical techniques for handling electromagnetic engineering problems. To this end, the material is arranged according to similarity of technique rather than according to relevant electronic devices. Theoretical to the extent that theorems are proved and formulas derived, the book also contains illustrative practical examples. "Time-harmonic" is used in the title to indicate that only sinusoidally time-varying fields are considered. The mathematical techniques discussed include wave functions—plane, cylindrical, and spherical—and perturbational and variational techniques. The final chapter is devoted to microwave networks.

TECHNICAL LITERATURE

The following recently issued technical literature may be of interest to readers of *Electrical Engineering*. All inquiries should be addressed to the issuers.

CORRECTED OPTICAL PYROMETER READINGS. National Bureau of Standards Monograph 30, by D. E. Poland, J. W. Green, and J. L. Margrave. This book of tables enables pyrometer users to convert observed temperature immediately to true temperature, if the effective emissivity of the material being observed is known. Conversely, the table can be used to determine the effective emissivity if the true temperature is known, by comparing this temperature with the pyrometer reading. True temperatures have been calculated for emissivities ranging from 0.02 to 0.98; observed temperatures are available from 1,000 to 39,900 degrees Kelvin. The 74-page booklet is available from the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C., for 55¢.

SCIENTIFIC INFORMATION NOTES, Volume 3, Number 2. Published by the National Science Foundation (NSF), this booklet gives information on current and future activities of the Foundation. Information is included on meetings and conferences here and abroad, research and development projects supported by NSF, science information activities abroad, and publication notes. The 23-page booklet is available from the Superintendent of Documents, United States Government Printing Office, Washington 25, D. C., for 25¢.

PROCEEDINGS OF THE 1961 ELECTRONIC COMPONENTS CONFERENCE. This book covers sessions on "Transistors and Solid-State Devices," "Progress in Component Reliability," "High-Voltage Components," "Microwave Components," "Components, Resistors, and Capacitors," and "Microminiaturization, Space Components, Materials and Related Devices." Included in the 540-page book are 38 papers. It is available from Order Department, American Institute of Electrical Engineers, Engineering Societies Building, 33 W. 39th St., New York 18, N. Y., for $9.

COMPONENTS HANDBOOK. This handbook gives information on electromechanical and electric switching devices and components. The book is divided into six sections, and includes relay and switch theory and terminology, switching and control circuits, and reference, application and technical data. The section on reference information presents common circuit symbols and contact forms, showing both the schematic symbol and the circuit symbol. Product specifications are given for electronic components of the publishing company. The handbook is available at $1 from the Manager, Component Products, Electronetics Division, North Electric Co., Galion, Ohio.

FERRITE STANDARDS *No. 21-61.* This standard gives preferred dimensional specifications for small ferrite electronic cores. It defines the common terms that apply to magnetic cores of ferrite, and lists preferred standard dimensions and dimensioning practices for plain and hollow cores; threaded, sleeve, toroidal, antenna and cup cores; cores with inserts, and coil forms. Copies of the standard may be obtained from the Ferrite Manufacturers Association, 60 E. 42nd St., New York 17, N. Y., for 50¢ each.

FACT SHEETS ON UNITED STATES NUCLEAR POWER PROJECTS. These fact sheets have been made available in a revised form by the Electric Companies Public Information Program. This edition represents a complete revision of the fact sheets issued June 1960, and includes all nuclear power projects in the United States. The projects are classified by reactor types, and notes are given on classification of reactors and on each type. The facts given on each project include the owner, contractors, operators, estimated costs, fuel charges, information officers, and other pertinent data. Copies of the 52-page booklet are available from Bozell and Jacobs, Inc., 230 Park Ave., New York 17, N. Y., for $1 each.

OPTIMUM USE OF ENGINEERING TALENT. Thirty-one executives have contributed to this volume, which attempts to analyze the problems of managing technical personnel. The book notes that engineers have developed "a cynical attitude" toward their employers as a result of management's tendency to treat them as "a commodity which is periodically in short supply or oversupply." One purpose of the book is to show how these attitudes can be avoided or changed. Among the topics covered in detail are methods of recruiting engineers, financial compensation, and professional development training programs. Priced at $6 to AMA members and $9 to nonmembers, this 416-page volume is available from the American Management Association, 1515 Broadway, New York 36, N. Y.

SAFETY GUIDE. SG-9 is the designation of a safety guide on disposal of hazardous industrial wastes. The pamphlet outlines recommended safe practices and procedures for disposal of flammable liquids, toxic and corrosive materials, and other substances which may create problems of air or stream pollution. Recommendations are made for organization of plant personnel responsible for disposing of wastes, as well as several methods of disposal. SG-9 is available from the Manufacturing Chemists Association, Inc., 1825 Connecticut Ave., N. W., Washington 9, D. C., for 20¢.

RCA REVIEW, *Volume XXII, No. 1.* This publication contains 13 papers on electric energy conversion by the new and direct methods that have been developed during the past 20 years. The papers deal with such subjects as the direct conversion of heat to electromagnetic energy; spectral response of photovoltaic cells; and plasma synthesis and its application to thermionic power conversion, among others. The book is available from the RCA Review, Radio Corporation of America Laboratories, Princeton, N. J., and is priced at 75¢.

TRANSFORMERS. This is the title of Volume 37 in the electronic technology series. The volume is edited by Dr. Alexander Schure, and is intended to give technicians and students a working knowledge of transformers. Transformer theory is analyzed as it is used in electronic equipment, with mathematical examples. Beginning with a discussion of the basic magnetic principles of the transformer, the book progresses to transformer design and construction. In this connection various specific subjects, such as waveforms, are discussed. Power transformers are studied in detail, and audio transformers are covered, with emphasis on such important topics as transistor transformers. High-frequency transformers and several special devices are also treated. Priced at $2, the book is available from John F. Rider Publisher, Inc., 116 W. 14th St., New York, N. Y.

ASM REVIEW OF METAL LITERATURE, Volume 17. This review contains more than 11,000 annotations of articles, technical papers, reports and documents which were published in scientific, engineering, and industrial journals and books throughout the world during 1960. Edited by Marjorie R. Hyslop, the book is divided into 20 sections covering different areas of materials and process engineering and technology, and includes addresses of publications as well as subject and author indexes. The 1,342-page book is priced at $25, and is available from the American Society for Metals, Metals Park, Novelty, Ohio.

STANDARDS OF THE ALUMINA CERAMIC MANUFACTURERS ASSOCIATION. This book of standards is of interest to those concerned with new uses and advances in the application of ceramic materials in the fields of nucleonics, electronics, high-temperature uses, etc. Much of the material in this booklet is being published for the first time. Included are special sections on test methods, design fundamentals, and quality assurance standards, among others. Priced at $1, the Standards is available from the Alumina Ceramic Manufacturers Association, 53 Park Place, New York 7, N. Y.

OTS REPORTS. The following reports have been made available to the public by the Office of Technical Services. *Model 16 Automatic Blood Pressure Measuring Instrument.* The Air Force has developed a device which automatically monitors blood pressure and provides an electrical signal which can be recorded or telemetered. Its unique feature is the use of transistor logic for performing the program functions. Order No. PB 161 707, 51 pages, $1.50. *Ceramic Tubes Developed for External Heat Sources.* The problems of developing an electron tube structure capable of sustained operation by means of an external radioisotope heat source are discussed. Adaptation of existing structures and heat sources for demonstration are reported, and suggestions are made for a practical tube. Order No. PB 171, 492, 43 pages, $125. *Methods of Measuring Emittance.* Methods and equipment used in emittance measurement are described in this study of the radiant-heat transfer field. A general survey of the better-known methods is given, and references are given for those seeking more detailed information. Order No. PB 161 228, 22 pages, 50¢. *Refractory Metals in Europe.* The results of a study of research, production, and uses of refractory metals in Europe, including Russia, are given. Order No. PB 161 223, 6 pages, 50¢. *Compliant Electrodes for Dielectric Measurements.* Compliant electrodes, developed in an Army research program to give improved surface contact in measuring dielectric properties, show more reproducible results than conventional metal electrodes. Order No. PB 161, 15 pages, 50¢. *Synthesis and Purification of Dielectric Materials.* This Air Force report recounts the second year of progress in a research program aimed at developing a nonconducting material suitable for electrical insulation. Order No. PB 171 364, 77 pages, $2. OTS, U. S. Department of Commerce, Washington 25, D. C.

INSTANT TWO-WAY CONVERSION TABLE. This table was designed to permit a quick, accurate conversion from inches to millimeters and vice-versa. It should prove useful to engineers concerned with the increasing exchange of material between countries which use different units of measure. Measurements are given from 0.001 inch to 10 inches in increments of 0.001 inch, with corresponding values in millimeters. The "International Inch" is used as a factor, and an explanation for interpolation to 0.0001 inch and 0.01 millimeter are given. By decimal manipulation, the table may also be used for conversions from 1 to 10 inches and from 254 to 2,540 millimeters. It is available from E. Joe Penn, 4910 Carson Ave., Indianapolis 10, Ind., for $1.

ENGINEERING SOCIETIES PERSONNEL SERVICE, INC.

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These items are listings of the Engineering Societies Personnel Service, Inc. This Service, which cooperates with the national societies of Civil, Chemical, Electrical, Mechanical and Mining, Metallurgical and Petroleum Engineers, is available to all engineers, members or non-members, and is run on a nonprofit basis.

If you are interested in any of these listings, and are not registered, you may apply by letter or resume and mail to the office nearest your place of residence, with the understanding that should you secure a position as a result of these listings you will pay the regular placement fee. Upon receipt of your application a copy of our placement fee agreement, which you agree to sign and return immediately, will be mailed to you by our office. In sending applications be sure to list the key and job number.

When making application for a position include eight cents in stamps for forwarding application.

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MEN AVAILABLE

New York Office

ELECTRICAL ENGINEER, B.S.E.E., Registered P.E., N.Y.S. 14 years' broad experience in design and manufacture of switchboards, panelboards and switchgear equipments with leading U.S. manufacturer, including one and a half years as general manager of company's switchgear assembly plant in Latin America. Will relocate. E-254.

CONSTRUCTION SUPERINTENDENT OR FIELD ENGINEER, ELECTRICAL, B.S.E.E. University of Michigan. Thirty years' experience design, construction power plant, transmission lines, substations and distribution systems. Foreign and Domestic. Salary open. Location open. E-255.

SALES MANAGER OR ENGINEER, B.E.E., 34. Eight years' industrial sales and sales oriented positions—established foreign plant, sales and service staffs for European representatives. Location, Prefer New York City. E-256.

Chicago Office

DIVISION GENERAL MANAGER, GENERAL SALES MANAGER, MANAGER OF PRODUCT PLANNING, B.S.E.E. plus Business Administration; 45. Recently general sales manager commercial refrigerators; three years' manager of program development for research organization; nine years' engineering manager for a manufacturer of electrical equipment and nine years' manager of product sales of meter and instruments division of large manufacturer. Salary, $18,500. Location, West, Midwest, East. E-2203-Chicago.

GENERAL MANAGEMENT OR PROGRAM MANAGEMENT, B.S.E.E., M.B.A.; 35. Nine years' of progressively increasing responsibility in military aerospace systems including program management, long range planning, sales, engineering design and staff work. Programs $5 to $150 million/year. Three years' related experience. Salary, $25,000. Any location acceptable. E-2202-Chicago.

ELECTRICAL ENGINEER (Power), B.S.E.E.; 25. Experience in public utility system operations and dispatching; maintenance of electrical and mechanical equipment. Salary, $6500. Location, open. E-2201-Chicago.

ENGINEERING MANAGER, B.S.E.E.; 55. Engineering manager R & D synchronous flux motors and generators. Factory manufacturer motors, Ch.EE, motors development and design engineering, patents and technical articles. Salary open. Location, U.S.A. E-2200-Chicago.

ELECTRICAL ENGINEER, B.S.E.E., Registered P.E., 46. 20 years' in design, or design supervision of electrical utility generating, transmission and distribution facilities and chemical process plants; including preparation of estimates and specifications. Salary open. Location, Midwest. E-2199-Chicago.

San Francisco Office

MANAGER, ASSISTANT ENGINEER, EE, age 39. Ten years' experience design, development of motors fractional to 2000 AC and DC. Prefer any location. Home: California. $13,000. Se-1890

SUPERVISOR, PHYSICS AND MATHEMATICS, age 46. Over two years' experience in the development, modification and application of reactor nuclear instrumentation. Seven years' in applied research of dielectric phenomenon and the application of radioactive materials to industrial uses. Eight years' in development modification and application of electrical instruments for measuring electrical and magnetic parameters of motors and transformers. Prefer any location. Home: Idaho. $13,500. Se-1167

CONTACT ENGINEER, ELECTRICAL ENGINEER, degree, age 44. Diversified experience in power design and utilities, field negotiation. Good address, fluent French, German. References. Seeks position as Contact Engineer, representative for West Coast, East Coast or foreign assignment. Se-717

TRAINEE, TECHNICIAN, PHYSICS, ELECTRONICS, age 28. Recent graduate with maintenance experience in electronics. Prefer San Francisco Bay Area. Home: California. $500. Se-181

OPERATIONS, SALESMAN, APPLICATIONS ENGINEER, EE, age 26. Over two years's operation and emergency maintenance of 5KW and 75KW transmitters. Prefer West Coast. Home California. $125 week. Se-169

ENGINEER, Registered professional engineer thirty years. Engineering design manufacturing, executive and sales in electric power and distribution equipment. Last five years' chief engineer transformer plant. Salary open. Prefer California. Home: California. AIEE, NSPE. Se-165.

SALES ENGINEER, electrical, age 27. Over two years' sales experience with good sales record to industrials, contractors, engineers and electrical distributors, selling electrical wire, cable cranes and hoisting machinery, materials, handling equipment. Prefer San Francisco Bay Area. Home: California. $600 up. Se-128.

MANUFACTURER'S REPRESENTATIVE, registered professional engineer in California. Background thirty years' engineering, manufacturing, executive, sales, electric power and distribution equipment in Western United States. Wide utility acquaintance. Will cover territory, select and supervise agents and provide technical sales instruction. Home: California. Se-165

PRODUCTION ENGINEER, EE, age 36. Four years' experience preparing production layout for work shop, first two years' mostly mechanical then electrical. Three years' experience on final assembly lines dealing with radio and electronics. Four years' experience in circuit layout of toll circuits. Prefer any location. Home: Canada. $600. Se-1507

INSTRUMENT SYSTEMS ENGINEER, electrical, age 44. Ten years' experience with design, application and installation of industrial and nuclear instruments. Seven years' naval experience with communications and radar. Prefer San Francisco Penninsula. Home: California. $1100. Se-1412

FIELD SERVICES ENGINEER, EE, age 49. Experienced in design of switchgear, circuit breakers, controls, quality erection engineer for all forms electrical machinery, project engineer, set up and operate acceptance tests, suggest field engineering assignments. Prefer any location. Home: California. $10,000. Se-1327

FIELD APPLICATION PLANT ENGINEER, EE, age 28. Over three years' experience including research and development on electrical control, field work on percipitators and plant engineering (automation of spot welding equipment, layout of equipment, some power and light work). Prefer Northern California. Home: California. $575. Se-1340

DESIGN RESEARCH DEVELOPMENT ENGINEER, EE, age 54. Thirty years' experience in development, design, application, production management and engineering management in manufacture of A-C and D-C rotation machinery and its allied control equipment. Prefer United States. Home: California. $20,000. Se-1626

SALES MANAGER, EE, age 34. Eleven years' experience as district representative in charge of territory, supervised activities of engineers, some sales contact in construction machinery. Prefer West Coast. Home: California. Se-1561

POSITIONS AVAILABLE

New York Office

PROJECT ENGINEERS, B.E.E. or B.S. in Physics, advanced degree desirable, with a minimum of seven years' experience in research, design and development of UHF and VHF systems. Wideband background particularly desired. Supervisory ability, capable of preparing estimates for new projects, customer liaison, etc. Salary, to $14,560. Company pays placement fees and interview expenses. New York suburban area. W438.

SENIOR ENGINEER, Special Laboratory Instruments, minimum of B.S. in E.E. or Physics, advanced degree preferred, plus five years' designing and building electro-optical scientific laboratory instruments. Requires keen technical understanding plus a practical ability to produce hardware. Salary, $10-$14,000. Relocation expenses paid; may negotiate fee. Connecticut. W436(b).

RESEARCH PHYSICIST OR RESEARCH ENGINEER, B.S. or M.S. in Physics or Electrical Engineering, with none to five years' experience in research and development, preferably in instrumentation, electronics and control systems. Duties as above with particular reference to the physical properties of fibers, yarns and fabrics and to the dynamics and uniformity of their processing. Midwest. W434(b).

SUPERINTENDENT, Plant Operation, Buildings and Grounds, for a large medical center, graduate mechanical or electrical, with five to ten years' experience in maintenance work. Will administer and direct program involving maintenance of buildings and grounds, equipment and distribution lines for steam, hot water, plumbing, electricity, refrigeration and sanitation; compute costs, schedules and expedite operations and repairs, supervise emergency and major repair jobs and periodically inspect equipment and buildings; prepare engineering maintenance budget estimates. Salary, $9-$12,000. New Jersey. W432.

JOB ENGINEER, graduate electrical, for firm of architects and engineers specializing in design and construction of industrial plants for all electrical design on a project. Should have potential to grow and will do some analysis and

(Continued on page 37A)

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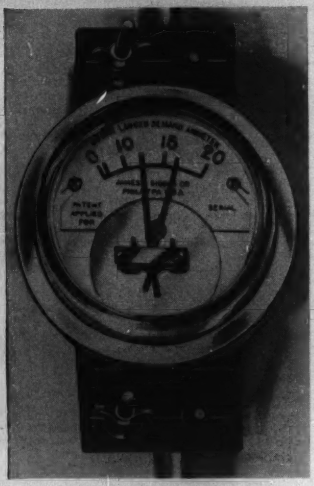
Transformer Load Indicator . . .

This low-cost demand ammeter will indicate 95% of the magnitude of a current charge which has held constant for 30 minutes at an ambient temperature of 67 F. A pointer follows current



changes while a red maximum reset pointer indicates the greatest value obtained since the last reset. Intended for use on 25-kva transformers having 2,300-volt primary windings, the instrument requires no electrical connection and may be attached by securing two J-bolts and snapping the laminated core into place over the conductor. *James G. Biddle Co., 1316 Arch St., Philadelphia 7, Pa.*

Distortion Adjuster . . .

Model *20/20* was designed to correct waveform defects in any television, radar pulse, sine wave, or wide-band complex waveform system. For broadcasters, it offers a practical, commercially priced system which eliminates transmission distortion from color and monochrome, composite and noncomposite signals, in any region of the video spectrum regardless of repetition rate. Known as a "time domain equalizer," the equipment uses the "paired echo" principle, in which any waveform is considered as the resultant of several paired echoes, each a replica of the signal, but advanced or delayed in time. Waveform defect correction is accomplished by synthetically generating echoes from the distorted waveform itself and adding these in proper amplitude and phase to the main signal to cancel out the unwanted portion of the signal. *Telechrome Mfg. Corp., 185 Dixon Ave., Amityville, L. I., N. Y.*

Load Break Switch . . .

The *ARI-60* is designed to provide distribution switching with operating and load-breaking capabilities usually found only in power-class switches. Built for use at 600 amperes in rating of 7.5, 15, and 23 kv, the apparatus is essentially a small power-class switch incorporating three insulator stacks with a vertical blade motion controlled by rotation of the rear stack. In operation the accepted system is used, wherein the blade first rotates on its own axis to relieve contact and then is elevated to the open position. *James R. Kearney Corp., 25th & Division Sts., Melrose Park, Ill.*

Stainless Clad Aluminum . . .

After extensive field tests this company can now offer the metalworking industry molecular-bonded stainless-steel-clad aluminum in sheet form. Unlike metals joined by casting, the molecular bond unites the two dissimilar metals into a single material having the desirable characteristics of both metals. With no technical limitations as to gauge or to content ratios of stainless to aluminum, metallurgical characteristics are excellent for deep drawing, stamping, beading, spinning, brazing, and welding. *Fairmont Aluminum Co., Box 912, Fairmont, W. Va.*

Vibration Damper . . .

This polyvinyl spiral was designed for small-diameter electric distribution lines ranging in size from No. 4 (0.250 inch) to 4/0 (0.563 inch) to arrest Aeolian vibration, the primary cause of chafing damage to tie wires, armor rods, and conductors. Damping is achieved through the "free response" principle where a 1-piece, helical spiral attached to the line with the weight evenly distributed is sufficient to stop all vibrations. *Preformed Line Products Co., 5349 St. Clair Ave., Cleveland 3, Ohio.*

Modular Terminal Wiring Block . . .

The Termi-Blok was designed to eliminate such fundamental limitations usually found in barrier and terminal boards as inadequate provision for density potential in multiple-wire applications, the need for cumbersome tools to insert or remove wires, and the use of a modular design concept necessary for many variations in stack configurations. These new terminal blocks are modular 3-circuit common and 6-circuit common insulated cage assemblies which fit into an aluminum tract. Current rating is 35 amperes continuous current, or maximum wire temperature of 105 C. *AMP Inc., Eisenhower Blvd., Harrisburg, Pa.*

Residual Magnetism Indicator . . .

A new pocket instrument that instantly measures the degree of residual magnetism in steel tools, parts, and structures, can be used to show residual magnetism levels required for "[illegible] free" parts cleaning. It also can be used to measure hardened steel parts that tend to pick up magnetism from magnetic chucks, machine tools, and conveyors. Magnetic polarity is indicated by deflection of the pointer on a 20-0-20 scale. *R. B. Annis Co., 1101 N. Delaware St., Indianapolis 2, Ind.*

Temperature Controller . . .

This portable temperature controller has a sensitivity range of —100 to +300 C and is accurate to 0.5 C. The unit has a rated load of 15 amperes on both heating and cooling cycles. Included with the *N-300* is a fast-response time probe completely sealed in a stainless steel housing rendering the unit adaptable for use in contaminated atmospheres or corrosive liquids. *Omtronics Mfg., Inc., Box 1419 Peony Park St., Omaha 14, Neb.*

Low-Voltage Bushings . . .

From 69-kv down to 15-kv service, these new Class GK oil paper transformer bushings will complement the Breaker-Tran line by covering the common dimensional requirements for transformer bushings included in Table 3, ASA standard C76.1a-1958. In each voltage class the 400-ampere, 16½-inch-oil-level and the 400-ampere, 21-inch-oil-level bushings employ tubular conductors, draw-lead terminals and no stud below the end cap. The 1,200-

ampere, 21-inch-oil-level transformer bushing uses a solid conductor that extends below the lower end cap and above the oil reservoir for attachment of leads. *Ohio Brass Co., Mansfield, Ohio.*

(Continued on page 26A)

EASILY HANDLED—Neat, compact arrangement of 2300-volt power feeders shows how easily Loxarmor cables are handled. These circuits serve a new 15,000 kva "packaged" substation.

A LOOK INSIDE—This cut-away shows details of the quality construction that is part of every Loxarmor cable. An additional advantage is available in an Okoseal (polyvinylchloride) jacket which can be supplied over and under the Loxarmor where environmental conditions warrant.

LOXARMOR®—the interlocked cable that bends itself to your will

You're the boss when you specify Loxarmor, Okonite's interlocked armor cable. Whether you require galvanized steel, aluminum, bronze or copper protection, Loxarmor is manufactured to your specifications. And Loxarmor cables are easily handled at both vertical and horizontal bends, as well as in crowded locations where circuits must be bent around piping and other apparatus.

Because of its installation economies, Loxarmor is finding increasing use in primary and secondary feeders, power and lighting circuits, station auxiliaries, control circuits, and motor circuits in place of rigid conduit systems.

Here are a few of the many advantages of Okonite Loxarmor cables:

Lower material and installation costs save money . . . additional circuits are easily added . . . circuits are easily rerouted . . . accessibility of Loxarmor reduces downtime . . . flexible, compact construction reduces space requirements. And the strict quality control under which Loxarmor is made, contributes to its continued record of superior service in the field. It all adds up to Okonite Cable'bility* —the ability to design and manufacture electrical cables that give outstanding performance.

To learn more about Loxarmor write for Bulletin EG-1090. The Okonite Company, Subsidiary of Kennecott Copper Corporation, Passaic, N. J.

*Cable'bility . . . cable craftsmanship since 1878

***where there's electrical power . . . there's* OKONITE CABLE**

8575

FLUCTUATING LINE VOLTAGES giving you trouble?

—keep 'em steady with a GLENN Line Voltage Compensator

100 kva Line Voltage Compensator installed at radar station operates on 3-phase input of 208v ±10%, delivers 208v ±1% at 300 amps, with no sine wave distortion.

You can cut line voltage fluctuations of ±10% to a mere ±1% with an economical, easily-installed GLENN Line Voltage Compensation Unit.

They're self-contained, convection-cooled units that work automatically and reliably, require little or no maintenance. They are available for all single or 3-phase line voltages to 600 vac, in output ratings to 400 kva (100% duty cycle)—and may be paralleled for higher capacities. Response time is adjustable.

Glenn Line Voltage Compensators pay off wherever line voltage jumps around to upset processing, control, testing or equipment performance. If you have problems like these, why not write us now for detailed information and a quotation?

WANT DC? Glenn fixed or variable-voltage dc power supplies are available for motor drive and speed control, powering magnets, instruments, test stands—for electrolytic refining, electroplating, de-tinning, etching. Write for literature.

5

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644 South York • Elmhurst, Illinois

EASTERN OFFICE
615 Riverwood Avenue • Point Pleasant, New Jersey

(Continued from page 24A)

Electronic Scale . . .

With an indication accuracy of ¼%, this scale for weighing scrap metal furnace charges has a capacity of 250,000 pounds plus tare weight of the empty car. In operation a self-propelled car stops on a weigh bridge supported by four electric load cells. Here the load is indicated simultaneously on an adjustable preset indicator in the scale house and a remote indicator placed so the crane operator can watch the charge weight. A preset alarm rings when the desired weight has been reached. *Gilmore Industries, Inc., 13015 Woodland Ave., Cleveland 20, Ohio.*

Adjustable Electronic Drive . . .

This inexpensive adjustable drive with a speed range of from 2:1 to 100:1 operates from a single-phase a-c supply. A pair of grid-controlled thyratrons and diode tubes provide full-wave rectified voltage to the drive motor armature. For precise speed regulations regardless of load, an *IR* drop compensating network is used. The drive also provides short-circuit protection, undervoltage and overload protection, a timed method of accelerating to preset speed, a regulated speed reference supply, and a fail-safe tube circuit on filament burnout. *Square D Co., 4041 N. Richards St., Milwaukee 12, Wisc.*

Electromagnetic Conveyor Router . . .

Principal elements of this novel automatic conveyor routing system are a keyboard to program and control the operation, a magnetic writing head attached to the conveyor's frame near the operator's station, a magnetic code patch mounted on the side of each container, and related actuating controls at each divert station. As a loaded container approaches the operator's station, the destination is selected on the keyboard which then translates it into magnetic memory logic. This is subsequently projected in code form to the writing head. As the container passes the writing head, the data is picked up and transferred to the container's magnetic memory code patch. The container then continues down the line until it reaches a station with a similar magnetic code which automatically activates a divert control switch. *Atronic Products, Inc., W. Conshohocken, Pa.*

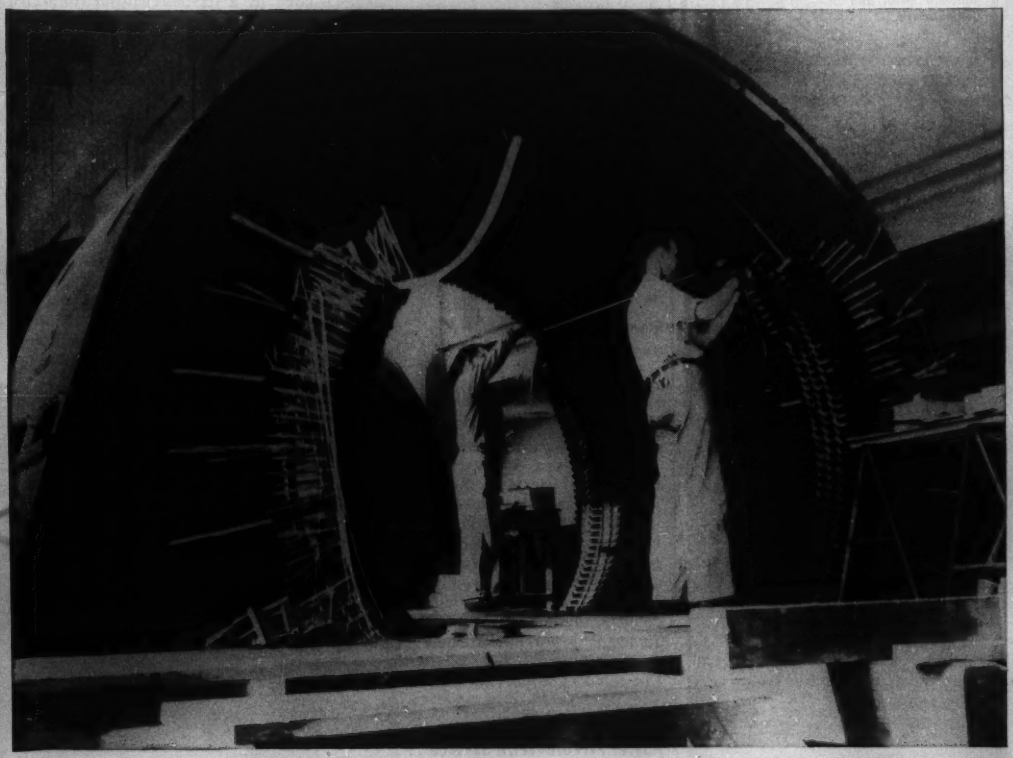
(Continued on page 28A)

Stator capacity increased by rewinding with NECCOBOND coils by National... *the specialists in electric coils / repair service*

Stator capacity of this 37,500 KVA Synchronous Condenser was increased at no change in temperature rise when the machine was rewound with new NECCOBOND coils having more efficient copper-slot ratio. Complete service included coil design and manufacture, installation and test. In addition, revolving field coils were completely rebuilt, installed and tested.

Whenever *you* need service on rotating electric machinery—whether large or small, whether you need a few coils or a complete rebuilding job—contact National Electric Coil. Our service is fast, thorough and dependable.

For information call National's Columbus Plant, HUdson 8-1151 or check the nearest National Field engineer.



NATIONAL COILS

National Electric Coil

COLUMBUS 16, OHIO • IN CANADA: ST. JOHNS, QUEBEC

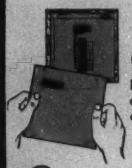
DIVISION OF McGRAW EDISON

GTC

UNITIZED
COMMUNICATION
EQUIPMENT for
POWER and INDUSTRY

Effective!
Reliable!
Economical!

1 Highly effective in extremes of ambient noise and temperature.



2 Plug-in units provide ease of installation, expansion and maintenance.

3 Transistors and rugged, industrial type components used throughout.

4 Central control cabinet, costly engineering and fabrication eliminated.

Wherever a highly dependable, voice communication system for use in high noise level areas is needed—you'll find GAI-TRONICS specified by name.

GTC is extremely flexible in application. Write today for a copy of our completely illustrated, descriptive booklet and name of nearest representative.

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GILBERT ASSOCIATES, INC.
ENGINEERS AND CONSTRUCTORS

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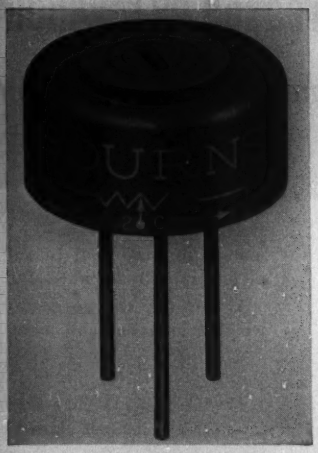


Low-Cost High-Quality Pot . . .

This new subminiature single-turn wire-wound potentiometer was designed for use in printed circuits and other modular-type applications where extreme angular resolution is not required. The main feature of this component is that it fills a gap between the truly commercial unit and the high-quality, high-price Mil-spec pot. Although it is not truly humidityproof, it does meet steady-state humidity requirements. *Bourns, Inc., 6135 Magnolia Ave., Riverside, Calif.*

Portable Psychrometer . . .

This improved instrument which quickly gives precise wet and dry bulb readings for determining relative humidity, absolute humidity, dew point, or enthalpy in air and other gases, uses tiny thermistor beads as resistance thermometer elements. Response time is rapid because of the small mass of the temperature sensing thermistor beads and because of the instrument's controlled air system. Since both wet and dry readings are usually obtained within 10 seconds, readings can be taken in confined spaces with limited air available for measurement. *Atkins Technical, Inc., 1276 W. Third St., Cleveland 13, Ohio.*

Faster Private-Wire Service . . .

Development of this automatic private wire system called Plan *115A* provides fast point-to-point transmission of data by enabling 20 stations in a circuit to send in quick automatic sequence. With priorities assigned to stations carrying heavier message loads, there is no "dead time" in the system. Messages are punched on standard paper tape, which feeds automatically into a transmitter. Meanwhile a selector switch is constantly "inviting" the 20 stations in the circuit to send by scanning each station in sequence. Automatic invitation requires less than ½ second per station. *Western Union Telegraph Co., 60 Hudson St., New York 13, N. Y.*

Pyrometer . . .

Operating on the basic measurement principle of sensitivity to light, this automatic pyrometer instantly measures and regulates temperatures to 4,000 C while recording changes to less than 1 degree. A light bulb inside the instrument adjusts to the brightness of the heat source. An electric current through the bulb provides the means of measurement. Temperature is regulated by a servomechanism connected to the heat source's power supply and to a detector sensitive to the brightness of the bulb. The detector adjusts signals from the heat source and the light bulb until they have reached the same level. *Atomics International, P. O. Box 309, Canoga Park, Calif.*

Protective Terminal Coating . . .

This peelable cellulose dip coating which can be easily removed provides a near-perfect electrical contact for bolted connections by protecting the carefully ground pad surface from dirt, oxidation, and the rigors of shipping, storage, and handling. Applied as a standard protection to ehv conductor accessories, the coating is optional on other accessories. *Rome Cable Div., Aluminum Co. of America, 1501 Alcoa Bldg., Pittsburgh 19, Pa.*

If you BUY, SPECIFY or INSTALL transformers, YOU SHOULD KNOW THESE IMPORTANT FACTS

Here Are Eight Sorgel Customer Benefits That Mean Positive Savings in Dollars

These engineered advantages show why Sorgel dry-type transformers are considered the finest in the electrical field. These quality features, and many others, assure you of economy in installation and operation.

- All coils have end filler protection in each layer to prevent movement of conductors under heavy loads and short circuit stress conditions.
- The transformer core and coil unit is specifically designed for low sound level. In units 15 KVA and larger, the core and coils are mounted on vibration dampening pads designed to suppress transmission of vibration to adjacent areas.
- Each unit is completely assembled, wired, and tested at the factory, ready for line and load connections eliminating any job-site assembly.
- All terminations are securely anchored, and solderless connectors are furnished on all transformers with terminal boards. Vacuum impregnated windings are brazed to the terminals.
- Connection covers are cushioned and easily removed by means of two captive bolts on small sizes, and four on larger sizes.
- Ventilating openings are designed to prevent accidental access to live terminal parts. Expanded metal is not used on sides, back or front.
- In Quiet-Quality units, performance data, such as core loss, copper loss, sound level, etc., is always equal to, or lower than, the guaranteed values submitted to the customer.
- Sorgel units are individually tested in accordance with NEMA standards. Certified tests are furnished upon request, to further substantiate the guaranteed data.

Contact your nearest Sorgel Sales Engineer for additional reasons why Sorgel units are truly your most economical buy - as quality pays, it doesn't cost.

SORGEL
SOUND-RATED DRY-TYPE
TRANSFORMERS

SORGEL ELECTRIC COMPANY

Since 1916 the pioneer in the development, manufacturing and application of sound-rated dry-type transformers

846 WEST NATIONAL AVENUE • MILWAUKEE 4, WIS.

Experienced sales engineers in principal cities

TRANSFORMER FOR YOUR EVERY NEED

CLIP AND MAIL FOR TECHNICAL BULLETINS.

- ☐ 611—Transformer Line
- ☐ 960—Substations
- ☐ 658—DC Saturable Reactors

Name_____

Title_____

Address_____

City_____

State_____

All units are built to meet or exceed latest standards of ASA, NEMA and AIEE. Sorgel provides the most liberal designs and a coordinated system of either Class B, F or H insulation with the most effective use of quality materials to assure continuity of service.

Sorgel is the leading manufacturer of quality Saturable Reactors used to regulate and control electric power for various manufacturing processes. Special features are: unusual wide control range, low D.C. requirements, low cost operation. Illustrated is a 150 Kva Reactor with recording and indicating instruments for automatic control.

Trade Literature . . .

Microminiature Connectors . . .

Series *600-2* printed-circuit connectors are small precision-designed card receptacles for microelectronic applications. Forty contacts with a 0.050-inch center-to-center spacing are mounted in only 1 11/16-inch long molding. Contacts are "Bellowform" type providing coil spring action grip over the entire contact area of printed-circuit boards. The contacts accept a 1/32-inch printed-circuit board or tape cable. Recommended test voltage at sea level is 900 volts rms, current rating 1 ampere. Terminations can be soldered or welded. For Technical Bulletin 600-2 write to *Electronic Sales Division, DeJur-Amsco Corp., 45-01 Northern Blvd., Long Island City 1, N.Y.*

Variable Transformers . . .

A compact 50/60-cycle powerstat variable transformer series has been introduced having output ratings up to 3.75 amperes with constant current loads and up to 5.5 amperes with constant impedance loads. Called the *21* Series, they feature: gold alloy plated commutator, functionally designed terminal arrangement for connection flexibility, terminal adapters for either soldered connections or push-on connectors, adjustable 3/8-inch solid metal shaft, square base design for increased strength and reduced over-all height and space behind panel. For 8-page Bulletin P6121 write to *The Superior Electric Co., Dept 21, Bristol Conn.*

"Endur-All" Distribution Transformers . . .

Operating and maintenance benefits of the *Endur-All* distribution transformers are described in a new bulletin. Features include a new design which reduces impedance by as much as 25%, new locked core-and-coil construction which eliminates 32 pieces of hardware, and 10% lighter and lower units for easier handling. The transformers have new high-gloss high-retention paint plus reusable gasketing for reduced maintenance; increased cooling duct area for better circulation, and a purer transformer oil which adds extra overload capability. Copies of Bulletin 61B9943 are available on request from *Allis-Chalmers Mfg. Co., Milwaukee 1, Wis.*

Miniature Thermocouples . . .

A new line of microminiature thermocouples—world's smallest and fastest temperature sensors—is described in this 6-page 2-color bulletin. It covers the design, construction, applications, and operating characteristics of these thermocouples, which have a probe diameter of only 0.014 inch and operate in a temperature range from cryogenic environments to 3,000 F. The bulletin includes drawings and photographs; circuit sketches; curves showing radiation error, time constant, and response times; a listing of types and model numbers, and temperature ranges. *Baldwin-Lima-Hamilton Corp., Philadelphia 7, Pa.*

Hardfacing Electrodes and Wires . . .

A 44-page brochure ADC 955 contains a cross-referenced, pictorial layout in which all the hardfacing materials are classified and illustrated according to use. The wear protection provided on industrial and construction equipment by the company's hardfacing alloys is discussed in detail. A description of each electrode is presented along with application data. Over 100 specific equipment parts that benefit from hardfacing are listed in an extensive section, together with the type of wear which each is subject and the alloy needed to protect it. *Air Reduction Company, Inc., 150 E. 42nd St., New York 17, N. Y.*

"Cradle" Relays . . .

Complete data with circuit diagrams, chassis layouts, and socket guide for its line of military and commercial *T154* "Cradle" relays have been published in the company's 4-page, illustrated bulletin. Open, dust cover, and hermetically sealed types with plug in, printed circuit, and hook-type solder terminals for the relays are described for 12 different mounting variations with contact arrangements up to 6-pole double-throw. Operating conditions for 5 ampere, 2 ampere resistive (1 ampere inductive at 29 volts, d-c; 115 volts, a-c) and low-level contacts are given as well as tables for coil resistance, sensitive and power operated data. *Allied Control Co., Inc., 2 East End Ave., New York 21, N.Y.*

"Hygromite" Moisture Meter . . .

This bulletin describes the Hygromite, a portable laboratory moisture meter which continuously monitors water vapor in gas. Performing with a full-scale accuracy of ±5%, the instrument measures vapor in ranges of 0–10, 0–30, 0–100, 0–300, and 0–1,000 parts per million. It is designed for use in many control applications, including the monitoring of gas in purge systems, the measuring of moisture in the helium used for precise chromatographic techniques, the monitoring of gas dryers in laboratories, the checking of water content in bottled gases, and the monitoring of natural gas in petroleum research labs and pilot plants. A special hydrogen electrolytic cell, supplied either with the instrument or on separate order, provides previously unobtainable accuracy in the monitoring of gases having hydrogen concentrations of more than 50%. A standard electrolytic cell is used to remove and electrolyze water in samples containing either no hydrogen or concentrations of the gas in proportions of less than 50% of the sample. For a copy of Bulletin 773 write to the *Technical Information Dept., Beckman Scientific and Process Instruments Division, Fullerton, Calif.*

Coaxial Relays—Switches . . .

A new 28-page, color catalog describes the company's standard line of *DK* coaxial switches and relays. Among the features are: résumé of the chief characteristics and operating principles of the coaxial switch; complete summary of 125 standard switches available from stock; details on production and custom engineering facilities, quality control processes; and information on sales and ordering. *RF Products, 33 E. Franklin St., Danbury, Conn.*

Plant Equipment Catalog . . .

A complete line of maintenance, safety, and production equipment is pictured and described in this 64-page 1961 Catalog No. 33. Buying data covering 110 different products are included. Typical items include rotary burs and files, metal-cutting saws, test instruments, electric etchers, and electric motor maintenance devices. *Martindale Electric Co., 1375 Hird Ave., Cleveland 7, Ohio.*

(Continued on page 36A)

DESIGN WITH ARNOLD 6T CORES... SAME-DAY SHIPMENT OF STANDARD DELTAMAX CORE SIZES

Arnold 6T tape cores (aluminum-cased and hermetically-sealed) offer you three very important design advantages. *One:* Maximum compactness, comparable to or exceeding that previously offered only by plastic-cased cores. *Two:* Maximum built-in protection against environmental hazards. *Three:* Require no supplementary insulation prior to winding and can be vacuum impregnated after winding.

Now we've added a fourth vital advantage: Maximum availability. An initial stock of approximately 20,000 Deltamax 1, 2 and 4-mil tape cores in the proposed EIA standard sizes (See AIEE Publication No. 430) is ready on warehouse shelves for your convenience. From this revolving stock, you can get immediate shipment (*the same day order is received*) on cores in quantities from prototype lots to regular production requirements.

Use Arnold 6T cores in your designs for improved performance and reduced cost. They're guaranteed against 1000-volt breakdown . . . guaranteed to meet military test specifications for resistance to vibration and shock . . . guaranteed also to meet military specifications for operating temperatures. The 6T hermetic casing method is extra rigid to protect against strains.

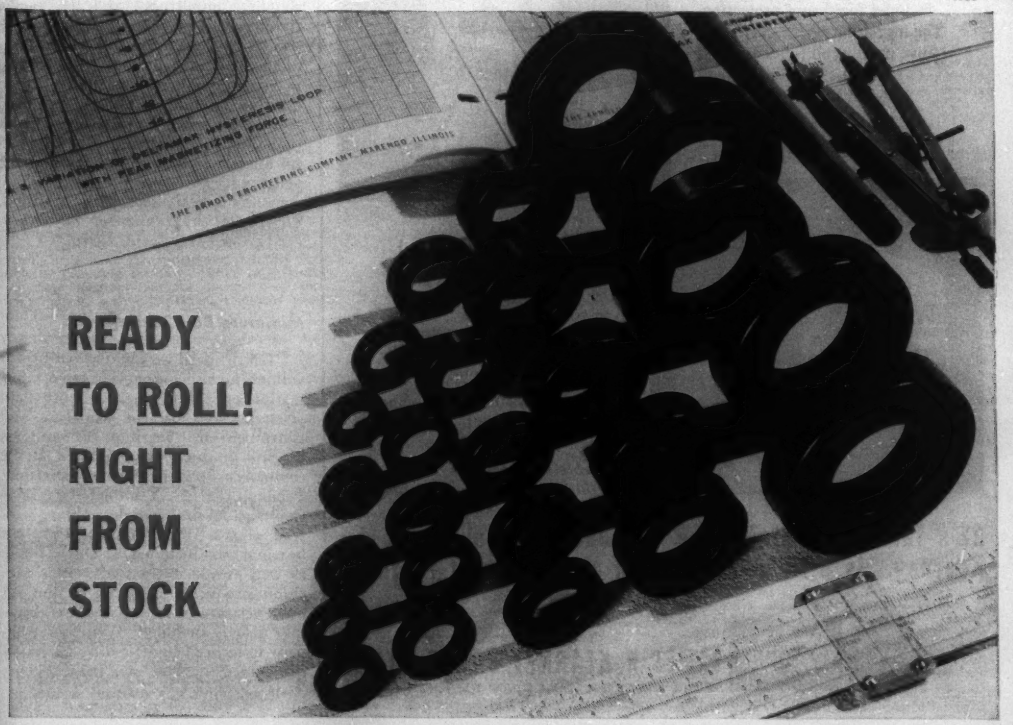
Let us supply *your* requirements. Full data (Bulletin TC-101A and Supplements) on request. • Write *The Arnold Engineering Company, Main Office and Plant, Marengo, Ill.*

ADDRESS DEPT. EL-7

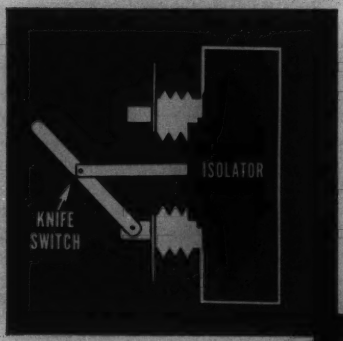
ARNOLD
SPECIALISTS in MAGNETIC MATERIALS

BRANCH OFFICES and REPRESENTATIVES in PRINCIPAL CITIES • *Find them FAST in the YELLOW PAGES*

1539



ISOLATORS
are the most practical disconnect you can buy!

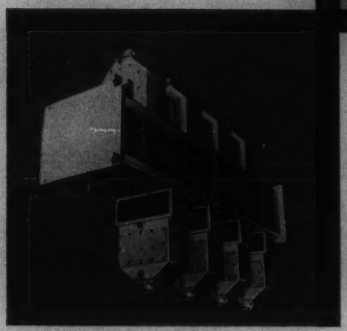


Isolators require the least space of any disconnect

. . . only ⅓ as much as an equally rated knife switch. ISOLATORS save on cubicle construction, floor space and installation time . . . lightweight, easy to install—come complete with all elements assembled in rigid frame.

Isolators are safe!

. . . the straight line action includes fool-proof protection. The insulating sleeve shields the live parts at all times and still shows a clearly visible gap when the switch is open.



Isolators are versatile!

. . . so compact, practical for switching centers that we've given a new name to a combination of bus duct and disconnect . . . the ISO-DUCT. Neat and handsome, excellent for both modern plants and replacements, ISOLATORS can be combined with potheads for any arrangement.

Available from 5KV to 15KV in ratings from 600 to 2000 amp.

3E's famous straight line disconnect...now made by Kearney...is still unmatched in all important features

KEARNEY **JAMES R. KEARNEY CORPORATION**
MELROSE PARK DIVISION • 25TH & DIVISION STS., MELROSE PARK, ILL.

PLANTS IN ST. LOUIS • MELROSE PARK, ILL. • FAYETTEVILLE, ARK. • GUELPH, ONT., CANADA • ST. THERESE, QUEBEC, CANADA

(Continued from page 32A)

Diode Catalog . . .

A new 12-page 3-color diode catalog describes more than 200 *1N* and *FD* series silicon Planar diodes manufactured by the company. It features several new products including *FD400*, a high-conductance ultrafast Planar diode with 500-mw power dissipation (forward conductance, 150 ma minimum at 1.0 volt; reverse recovery time, 75 millimicroseconds maximum, switching 200 ma). Also included in the catalog are the specifications for matched pairs and quads of diodes in current ranges of 10 μa to 50 ma, matched on forward voltage and assembled in epoxy resin. Matching is guaranteed over a temperature range of —55 to 100 C. *Fairchild Semiconductor Corp., 4300 Redwood Highway, San Rafael, Calif.*

Infrared Spectrophotometer . . .

This technical data sheet describes a new lightweight infrared spectrophotometer developed for airborne or satellite-borne spectral measurement applications. The instrument's spectrophotometric capability, light weight, compactness, and low power requirements make it suitable for such studies as the infrared boundary-layer phenomena of hypersonic vehicles and re-entering nose cones. Placed in an orbiting satellite, it can be employed to measure earth emissivity and solar radiation. The instrument is also useful for terrestrial measurements in the field, as it can be easily carried by one man and quickly set up on a tripod. *Electro-Optical Division of the Perkin-Elmer Corp., Norwalk, Conn.*

Miniature Ball Bearings . . .

This 64-page wire-bound multicolor volume furnishes comprehensive information on a full range of more than 500 types and sizes of miniature and instrument-size bearings, as well as bearing products manufactured at the company's Split Ballbearing Division, Lebanon, N. H. Complete specifications, actual-size and detailed easy-to-read cross-sectional drawings of ball bearings are included in the volume, as well as illustrations of MPB's precision products. A special section on nomenclature with explanatory drawings also is included. Write on company letterhead to *Miniature Precision Bearings, Inc., Precision Park, Keene, N. H.*

(Continued on page 38A)

(Cont'd. from page 23A)

reports. Salary, to $12,000. New York City. W426.

CIRCUIT ENGINEER, graduate electrical, to work spot assignments on electronic circuitry as service engineer for three different divisions of a manufacturing company. Salary, to $10,000. Connecticut. W425.

SALES ENGINEERS, for the application and sale of electronic components, i.e. potentiometers, precision potentiometers and relays. One year sales experience desirable. Factory training from four to five weeks on West Coast. Territories: One for Long Island and part of New York City; One for northern New Jersey and Westchester County. Apply by letter including salary requirements. W417.

MANUFACTURING ENGINEERS, graduate electrical, industrial and mechanical, with five years' experience in analyzing producibility and solving fabrication and assembly problems of military electronic and electro-mechanical equipment; familiarity with prototype and production manufacture techniques. Capable of writing test specifications and procedures. Heavy estimating on bid proposals, i.e. electrical and mechanical assembly and some machine and sheet meta. Salary, $8-$10,000. Company pays placement fee. New York suuburban area. W416.

ENGINEERS. (a) Project Managers, graduate electrical, for systems engineering department, military products division, for overall project responsibility, including design, prototype production, engineering direction, manpower and material estimating and scheduling, and customer liaison. Heavy background required in tele-communications systems, including wire transmission, tropo-scatter, space tracking, microwave and digital communications. Salary, $12-$16,000. (b) Project Managers, graduate electrical, for product engineering department, military products division, to be responsible for military communications product design and development. At least eight years' experience required in two or more of the following communications areas: RF transmission and receiving systems (UHF-Microwave), RF repeater systems (UHF-Microwave), base band systems (analog and digital multiplex), spectrum conservation techniques. Must be capable of assuming all phases of project responsibility, including design, schedules, etc. $12-$16,000. Company pays fees. New York suburban area. W415.

SUPERVISING PROJECT ENGINEER, graduate mechanical or electrical with five to ten years' experience on the design, calculations and packaging from the electronic and mechanical side of hearing aids. Salary, $12-$15,000. Connecticut. W412.

MARKET RESEARCHER, graduate electrical or electronics engineer, with four to six years' electrical or electronics experience. If no experience in market research work, should have strong desire to get into this field. Should be capable of assuming complete responsibility for projects, including the investigation of product problems, potential markets, or the need for new products. Salary, $9-$11,000. Company pays fee. Pa. W411(a).

ENGINEER TRAINEE, electrical graduate, for project engineering, with up to two years' experience in the electro-mechanical field. Salary $7500. Connecticut. W410.

ENGINEERS. (a) Electronic Engineer, Research and Development, B.S. in E.E. or Physics, with three or more years' experience in the design and development of electronic circuits, especially for switching and control, of which at least two years' should be in solid-state circuits. (b) Senior Electro-mechanical Engineer, Research and Development, graduate electrical or mechanical, with five or more years' experience in the design, development and testing of small electro-mechanical components such as relays, instruments, etc., with environmental testing to MIL specifications helpful. (c) Electronic Engineer, graduate electrical, with a minimum of three years' experience in development and design of electronic circuits for audio, video, pulse applications, at least two years' of which involved transistor circuitry. Newark, N.J. area. W407.

APPLICATIONS ENGINEER, graduate electrical, with at least one year of product development and design, or at least three years' laboratory technician work. Field or sales engineering experience acceptable. Newark, N.J. area. W406.

CHIEF ENGINEER, graduate mechanical or electrical, executive ability, to take charge of the engineering for food processing machinery company. Considerable automatic equipment to be developed on grain processing and considerable sheet metal design required. Salary, $10-$12,000. Midwest. W399.

DEAN, Department of Engineering, Foreign University, M.E. or E.E., ten years' of administration teaching or professional experience. Top scientific institution in Burma. Salary commensurate with American compensation. Must be U.S. citizen. F394.

PROJECT SUPERVISOR, B.S. in E.E., with at least seven years' experience in the development of electrical-electronic devices including dictating equipment and similar sound storing reproducing devices. Salary, $8500-$10,000. Northern New Jersey. W388.

ENGINEERS. (a) Product Engineer, M.S.E.E. or Physics preferred. Minimum of eight years' experience in design and production of high power tubes. Salary, to $17,000. (b) Department Head, M.S. or Ph.D. in E.E. preferred. Crossed field tube development and production, minimum of 12 years' experience. Salary, to $25,000. Company pays placement fees. New York suburban area. W387.

RESEARCH AND DEVELOPMENT ENGINEERS. (a) B.S.E.E. or Physics minimum; with a minimum of three years' experience in high power radar, radio or TV transmitters, consoles or power supplies or experience in video and pulse circuit design for modulators. (b) M.S.E.E. or Physics preferred, with minimum of five years' experience in traveling wave tubes and high power tubes. Company pays fees. Salary, to $14,000. New York suburban area. W386.

ASSISTANT TO CHIEF ELECTRICAL ENGINEER, graduate, for transmission and distribution from design and supervision of contract to work with contractors and engineers on job already started. Salary about $15,000, plus housing and local allowances. So. America. F371.

Chicago Office

DESIGN ENGINEER, with five to ten years' experience. Establish design practices and guide other engineers in the design of liquid filled transformers 5 KVA through 10,000 KVA, up to 69 KV. Salary, $8-$11,000. Employer will negotiate placement fee. Illinois. C8687.

LABORATORY SUPERVISOR, B.S.E.E., 30-45; coordinate laboratory technicians on rotating machinery, instruments and testing on electric motors. Will report to director of engineering—electric motor division for a manufacturer. Employer will pay fee. Salary, $8400-$10,200. Ohio. C8686(b).

DESIGN AND DEVELOPMENT ENGINEERS, graduate electrical engineer. One man on design and development. 400 cycle DC motors. Salary, to $15,000. One man on design and development of control equipment primarily electronically controlled. Salary, $12,000. For a manufacturer of precision equipment. Employer will pay fee. Ohio. C8671.

TV AND RADIO DESIGN AND DEVELOPMENT ENGINEERS, graduate electrical or mechanical engineer or equivalent, with five or more years' experience in design and development in one or more: TV receiver circuitry, amplifiers, transistors, tuners, audio, video, radio receiver, hi-fi-audio equipment and AM-FM receivers, pulse circuit transformers, RF filters, component design, radar systems, micro waves, servos, etc., for a manufacturer. Salary, $7800-$12,000 depending on experience. Employer will pay fee. No. Indiana. C8664.

APPLICATION ENGINEER, with two to five years' experience. Prepare quotations and proposals on electric motors and generators (up to 3500 HP); liaison between field sales, headquarters sales and engineering; limited travel. Salary, $6-$8000. Pa. C8661.

DIRECTOR OF ENGINEERING, graduate mechanical or electrical. To be responsible for all product development and design of small electro-mechanical devices, especially small electrical switches. Salary, $18-$25,000. New York, N.Y. Employer will pay fee. C8657.

San Francisco Office

FIELD AND OFFICE ENGINEER, about $6,000. Headquarters in San Francisco. EE, age under 30. Some familiarity wtih electrical construction installation, able to read plans and specifications and have some knowledge of methods. Train for ten weeks' in Eastern Headquarters, return to inspection work related to engineering aspects of fire protection. For a national organization district office. Deal with owners, engineers, architects, code officials. Some Northern California travel. Car required. Sj-5997.

PLANT ENGINEER, Salary commensurate, in San Francisco East Bay or Los Angeles, EE. Several years' experience in engineering new, additional or changes in manufacturing plant electrical systems. Able to assist in survey and report on plant needs. Prepare plans, layout work, direct and supervise electrical and mechanical maintenance workers. For a large manufacturer. Sj-6151.

MANUFACTURING ENGINEER, $550, in San Francisco East Bay, electrical shop background, age 32-50. Experienced in small electrical equipment shop. Electrical and mechanical knowledge of direct current panels, switchboards, controls, generators, motors (wiring, layout, drafting, circuiting bills of material, specifications). Also assist in procurement and shop production. Good opportunity in small growing business. For a manufacturer of DC generators, motors and controls. Sj-6153.

ASSOCIATE, ASSISTANT ENGINEER, $584-710, in San Francisco, for Associate California registration required, age to 70. Associate four years' experience, Assistant two years experience with utilities (phone, telegraph, water, electric, gas). Knowledge of operation of public utilities. Prepare standards, cost, rate of service, analysis, regulations, testify in court. Temporary three to four months, possibly permanent. Sj-6109.

DESIGNER, $450-500 depending on qualifications. In San Francisco, age to 50. Five to six years' industrial experience. To design project on power and light for offices, small buildings construction. For a consultant. Sj-6054.

DRAFTSMAN, $450 up, electrical background, age open, in San Francisco. Three years' electrical drafting experience required. Do electrical drafting on commercial, institutional buildings. Deal primarily with architects. For an electrical consulting engineering firm. Sj-6104.

ASSISTANT RESIDENT ENGINEER, $1200, in Africa, EE (utilities). Recent field experience building utility type electrical distribution system sub-stations and installing switchgear, instruments, panels, wiring and related equipage. Will represent owners in dealing with electrical general and sub-contractors. For a world wide engineering consultant. Sj-6136.

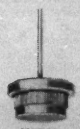
APPLICATIONS ENGINEER, $775-850, in San Francisco Peninsula and Europe, EE, age 25-40. Experience in engineering support to marketing, capable of working with European clientele, working knowledge of German and/or French. Understanding of fundamentals of frequency response and analysis, distortion, signal to noise, applications to magnetic tape recording systems (preamplifiers, transducers, port amplifiers) able to prepare formal proposals and to correspond in Europe. For a manufacturer. Sj-6162.

DESIGN, DEVELOP, TEST ENGINEER, EE degree required. Working knowledge of EE, physics, or related science. Carry out assigned projects with moderate supervision. To test equipment using transistorized circuits for communications systems both closed circuit and atmospheric propagation type. Design components and assemblies. For a manufacturer. Sj-6130.

APPLICATION, SALES ENGINEER, About $650 plus, in Contra Costa County, BS or MS in physics, math, ESc, EE. Recent graduate to three years' experience related to applications of electro-mechanical equipment, must be sales oriented and goodmath, preferably with knowledge of use and application of analog computers and systems. Will provide information to Research and Development, engineering firms, manufacturers, commercial users. For a manufacturer-designer. Sj-6112.

18 AMP SILICON RECTIFIERS as low as 58¢

This extremely low price is possible only because Motorola is producing millions of these rugged, 18 amp rectifiers for the automotive industry. These are quality units, designed to stand up under the toughest shock and environmental conditions. Hermetic glass seal and welded housing protects the precision-engineered silicon diffused-junction active area. Over six million are already in use.



MR322 Series

18 AMP SILICON RECTIFIERS

Five units offer PIV range of 50 to 400 volts. Reverse polarity units available. Package designed to cut your production-run assembly costs.

1N3208 Series

15 AMP SILICON RECTIFIERS

A stud-mounted version of the MR322 series available at comparably low prices. Five units offer PIV range of 50 to 400 volts. Reverse polarity units available.

FOR COMPLETE INFORMATION and prices on the above rectifiers . . . plus mounting methods for the MR322; write to Motorola Semiconductor Products Inc., Technical Information Center, 5005 East McDowell, Phoenix 8, Arizona.

MOTOROLA
Semiconductor Products Inc.
A SUBSIDIARY OF MOTOROLA, INC.
5005 EAST McDOWELL ROAD • PHOENIX 8, ARIZONA

(Continued from page 36A)

Insulated Cables . . .

Information on cables insulated with Okonex butyl-base high-voltage insulation is given in a 48-page reference manual. This service-proved butyl-base rubber insulation designed for multipurpose service up to 90 C, is extremely resistant to ozone, heat, and moisture. These insulated cables are said to carry heavier loads for a given size conductor or the same load on a smaller size conductor. Engineers should find the data on current carrying capacities, dimensions, and the various designs available helpful in designing and specifying efficient electric systems. *The Okonite Co., Passaic, N.J.*

Power Supply Catalog and Handbook . . .

A new D-C Power Supply Handbook and Catalog has been made available to anyone interested in d-c power design or procurement. This 24-page manual includes a step-by-step procedure designed for engineers who wish to calculate packaging dimensions for multiple d-c outputs. Considerations include spacing problems for modular d-c power supplies under various conditions of ambient temperature, external cooling, and rated current. The catalog details over 200 power supplies plus 1 million combinations of kitted modules. *Dressen-Barnes Electronics Corp., 250 N. Vinedo Ave., Pasadena, Calif.*

Pulse Tubes . . .

Characteristics and application data for high-vacuum switch tubes for pulse modulation make up this new brochure. It includes summarized characteristics for 19 tube types—15 triodes, 2 tetrodes, and 2 diodes—and a useful bar chart showing relative peak power capabilities for all tubes in the group. Peak power of tubes covered ranges from 7.5 kw for the *WL 6293* to 37.5 megawatts for the *WX 4450* and *WX 4361* tubes. For a copy of booklet ET 1273, write *Electronic Tube Div., Westinghouse Electric Corp., P. O. Box 284, Elmira, N. Y.*

115-Volt Servomotor Generator . . .

A new size 8 servomotor generator with both motor and generator wound for 115-volt 400-cycle excitation is described in a data sheet which also shows photos, electrical specifications for motor and generator, motor dynamics and environmental data. Outline and schematic drawings are included as well as the torque-speed curve. The new size 8 model *9008-1106-0* is of special interest to systems designers as it is a definite aid in simplifying circuitry, achieving greater reliability, and cutting costs of new systems. *Helipot Technical Information Service, 2500 Harbor Blvd., Fullerton, Calif.*

"Instrument Motor Quarterly" . . .

A new periodical, "Instrument Motor Quarterly," will contain articles on performance, selection, application, and maintenance of all types of fractional and subfractional horsepower motors. Editorial plans call for at least one article per issue to be authored by noncompany experts. The lead article of the first issue is on lubrication of instrument motors. Another feature will be a regular section titled "Instrument Motors at Work." Specific applications, with emphasis on how the motor contributes to over-all performance, will be covered here. Copies of the quarterly will be sent upon request to *Holtzer-Cabot Motor Div., 125 Amory St., Boston 19, Mass.*

Electronic Industrial Balancers . . .

A comprehensive catalog (Form 24-1) describes features and uses of all models and types of the company's electronic industrial balancers. It contains detailed and illustrated descriptions of models *703*, *704*, and *708* cradle-type balancers, which cover a weight range of from 8 ounces to 5,000 pounds, and diametral range of from ½ to 68 inches; model *2390* portable balancer; model *2409* single plane balancer; and model *2395* vibration monitor. *Industrial Balancer Department, Stewart-Warner Corp., 1826 Diversey Pkwy., Chicago 14, Ill.*

Electrolytic Conductivity Monitors . . .

Data Sheet E-95(3) describes the use of both the industrial and the portable conductivity monitors to measure electrolytic conductivity conveniently in process plants and in research work. Schematic diagrams illustrate the operation of the instruments and show how the industrial monitor connects to a typical control system. Complete specifications are listed for both models and ordering instructions are given. Automatic temperature-compensation assemblies, available for both instruments, are tabulated and illustrated. *Leeds & Northrup Company, 4934 Stenton Ave., Philadelphia 44, Pa.*

(Continued on page 42A)

THREE BILLION DOLLAR VOTE OF CONFIDENCE

in the future of OHIO

To keep pace with Ohio's dynamic growth, the state's eight investor-owned electric power companies will spend three billion dollars in the coming decade to double capacity. As much new generating capacity will be provided in the next ten years as was built in the past seventy-five.

If you are seeking a plant site, these facts are important for two reasons. First, this is solid indication of the confidence electric utilities have in Ohio's future growth. Second, you can be sure there will be plentiful, dependable electric power for your industry. Today, Ohio's generating capacity is 10.6 million kilowatts, and this state is the number one user of electric power in the nation.

Additional information detailing vital plant site factors is yours for the asking. Send the coupon below on your letterhead for two new booklets of solid facts: Statistical Abstract of Ohio: 1960 and Ohio, The Growth State.

Koder M. Collison, Director
State of Ohio, Department of Industrial and Economic Development
700 Bryden Road Columbus 15, Ohio

Please Send:
☐ Statistical Abstract of Ohio: 1960
☐ Ohio, The Growth State brochure

NAME _____ TITLE _____

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(Continued from page 38A)

Systems Selector . . .

Helpful data on epoxy insulation selection, and charts handling characteristics and physical and electrical properties are contained in the company's new systems selector. General-purpose casting and potting compounds, compression and transfer molding powders, dipping compounds, and conductive cements and coatings are listed. It is designed to fit Hysol's catalog, but folds open to make an easy reference wall-chart. *Electrical Insulation Division, Hysol Corp., Olean, N.Y.*

Transistor Test Equipment . . .

This 12-page brochure deals with a number of transistor testers of both the "go–no go" and absolute readout types. A description of typical testers and their salient features with test ranges, readout accuracy, and resolution is presented in the brochure. Described are the data logger, the type *4* tester, a "go–no go" transistor classifier, the automatic LV_{cox} tester, the low-current I_{cbo} tester, and the wide-range h_{FE} tester. *Fairchild Semiconductor Corporation, 545 Whisman Rd., Mountain View, Calif.*

Low-Pressure Switches . . .

Complete specifications, details, and prices on low-pressure switches and velocity actuated flow switches are described in this 30-page catalog. Products included are: low-pressure switches, vacuum switches, differential pressure switches, air flow interlock switches, water flow interlock switches, flow meters, manometers, air filter gages, etc. The catalog contains complete design information and dimensional diagrams. *The Henry G. Dietz Co., Inc., 12-16 Astoria Blvd., Long Island City 2, N. Y.*

Analytical Spectrometer System . . .

A technical brochure on the newly announced *A-60* Analytical Nuclear Magnetic Resonance Spectrometer System has been published by the company's Instrument Division. The 16-page brochure, illustrated with photographs and technical diagrams, includes discussions of range of applications, ease of operation and maintenance, theory of *A-60* operation with special emphasis on the unique Varian NMR Field/Frequency Control System, and performance specifications. *Varian Associates, 611 Hanson Way, Palo Alto, Calif.*

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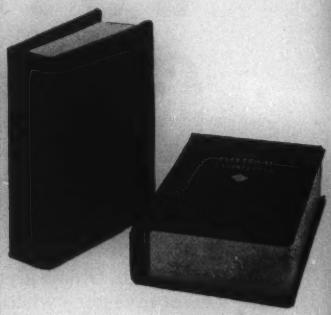

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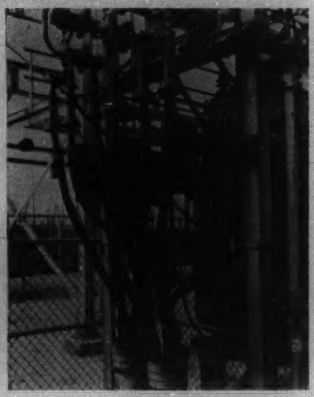
Industrial Notes...

Minnesota Mining & Mfg. Co.
St. Paul, Minn. . .

A pressure-sensitive, unsupported silicone rubber tape that combines the physical and electrical properties of silicones with ease of application is helping to solve high-voltage splice and



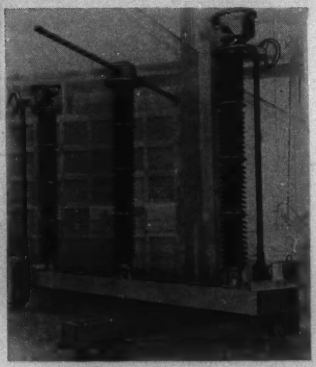
termination problems for several industrial contractors and maintenance crews. Terminations in the primary substation at a salt mine, reinsulation of silicone rubber cable at a steel mill and protection of primary bushings and potheads at a rayon mill are several of the situations where the tape is being used. Called "Scotch" brand electrical tape No. 70, it combines cured silicone rubber with a pressure-sensitive silicone adhesive. The tape is designed to be compatible with silicone cable insulation and can be used as a protective cover on standard terminations and potheads.

Burroughs Corp.
Detroit, Mich. . .

Burroughs Corporation recently announced a new electronic system for speeding and controlling the interchange of more than 50 million checks every day among U. S. Banks. Called the *B270* electronic data processing system, it represents another major advance in bank automation equipment developed to curb rising operating costs and to alleviate a shortage of trained personnel. Designed to provide automatic proof and transit operations, the *B270* will also convert "on–us" items to magnetic tapes for subsequent computer processing and may be used for automatic deposit analysis as well as account reconciliation services.

I-T-E Circuit Breaker
Greensburg, Pa. . .

The I-T-E Circuit Breaker Company has just completed shipment of what is believed to be the first two 345-kv double-break switches to be installed in this country. The switches are being installed in Consolidated Edison's Dunwoodie Substation, at the southeastern terminus of the 345-kv transmission line extending across New York State from the Power Authority's Lewiston Switchyard at Niagara Falls. The new switches are rated 1,300-kv BIL, 1,600-amperes continuous, and 70,000-amperes momentary rating, and are built on 5-inch bolt circle station post insulators. The switches, equipped with groundblades on both ends, are being mounted on 16-foot phase spacing. Rod gaps, as indicated by the ball-shaped electrode are located near the grounding switch mounting frame at each end of the switch. They are used



to control the negative impulse flashover to ground, to insure open gap coordination under all conditions. Radio influence tests on the switch indicate RIV values of less than 200 microvolts when a single-pole switch was tested with 225 kv from live parts to ground.

Texas Instruments
Dallas, Texas . . .

Texas Instruments Incorporated has announced that completely transistorized stereophonic sound systems are now a practical reality as a result of new device and circuit developments in the germanium power transistor field. A new stereo amplifier has been built by the company to prove the feasibility of "all-transistorized" systems. The TI system will provide 20 watts of sine wave power per channel from a distortionless amplifier circuit.

ITT
Nutley, N. J. . .

Development of two lightweight, portable atomic frequency standards (atomic clocks), which scientists say may prove to be accurate to less than 1 variation in 1,500 years, has been completed and delivery made to the U.S. Navy's Bureau of Ships by ITT Federal Laboratories, Nutley, N. J., research and manufacturing division of International Telephone and Telegraph Corporation. The present model weighs 55 pounds. Models now in the design stage, however, will weigh approximately 30 pounds. The basic element of the ITT clock is a small cell filled with the alkali metal vapor, cesium. The atoms of this vapor exhibit certain natural resonances to induced radio waves. Under controlled conditions, these resonances can be detected and made the basis for a very precise determination of frequency.

Gulf Oil Corp.
Pittsburgh, Pa. . .

Scientists at Gulf Research & Development Company, the research subsidiary of Gulf Oil Corporation, recently announced the development of the world's first automated catalyst analyzer. The new analyzer can be programmed to measure and record automatically the microstructure of refining catalysts. These mineral-like materials, whose inside surfaces contain billions of tiny holes and channels, are

used by the petroleum processing industry to convert vaporized hydrocarbons into lubricating and heating oils, high octane gasolines, and valuable chemicals.

(Continued on page 50A)

CLASSIFIED ADVERTISING

Regular classified advertisements set solid—no display—minimum 5 lines: $3.00 per line. No agency commission or cash discount allowed. Situation Wanted classified advertising for AIEE members: $2.00 per line, minimum 5 lines. Address orders to: Classified Section, ELECTRICAL ENGINEERING, 6th Floor, 33 West 39th Street, New York 18, N. Y.

When answering an advertisement, send all replies to box number specified, c/o ELECTRICAL ENGINEERING, 6th Floor, 33 West 39th Street, New York 18, N. Y., unless other address is given.

POSITIONS OPEN

PROFESSOR OR ASSOCIATE PROFESSOR of Electrical Engineering to teach and do research in the field of communications. Should have Ph.D., teaching and research experience. Write Box 56.

PROFESSORS, all levels. Ph.D. required. Solid-state, electromagnetics, and engineering analysis especially. Income, with research, competitive with industry. Graduate program as large as undergraduate. Mile-high, dry climate. Chairman, Electrical Engineering Department, University of New Mexico, Albuquerque, New Mexico.

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ELECTRICAL ENGINEERING TEACHING. Further expansion in a relatively young department provides attractive opportunities. Positions available to the rank of Associate Professor with salary range of $7500 on a base of nine months, commensurate with professional experience and graduate education. Supplementary professional opportunities are expected in a technical industrial area. Location: Southern New England. Box 132.

LIGHTING SALES REPRS. WANTED for quality line of architectural cold cathode lighting for coves; luminous/louverall ceilings and walls and custom lighting. Knowledge and experience in lighting sales engineering type of contacts with architects, engineers, lighting consultants and electrical contractors is a prime requisite. All territories open except greater New York City, Washington, D. C. and Connecticut areas. State territories covered and lines carried. Box 136.

RESEARCH ENGINEER for applied research work on basic approaches to small electric motors. Background required in Electromagnetics. Salary $7,000 to $9,000. Send resume to Personnel Manager, Black and Decker Mfg. Co., Towson 4, Maryland.

DESIGN ENGINEER, BSEE, for employment with electrical consulting firm. Experienced in motor controls, lighting power, general construction. Salary open. Uhl and Lopez, Box 8175, Albuquerque, New Mexico.

TRANSLATOR, technical, free lance, home assignments, must type. Previous experience essential. Preferably located in New York City area. State language, technical specialty, rates. Box 140.

ELECTRICAL ENGINEERS—with degree and 10 to 15 years experience in design and supervision of all phases of utility engineering required for position in near east. Salary open. Housing and transportation furnished with other Company benefits. All replys held confidential. Send complete resume of qualifications and personal information to: Miner and Miner International, Inc., P. O. Box 748, Greeley, Colorado.

ELECTRICAL ENGINEER—Large automobile manufacturing firm in Midwest has immediate opening. Require B.S. in Electrical Engineering with industrial plant experience to follow automated machinery installation and plant engineering design including power distribution, lighting, etc. Age range 25-45. Send complete resume and approximate salary requirement to Box 144.

DEPARTMENT HEAD. Head professor for 12-man E. E. department. Excellent opportunity for energetic and progressive Ph.D. with experience and potential to build, administer, and participate in a balanced program of teaching, research, and extension. Box 145.

POSITIONS WANTED

PROFESSOR OF ELECTRICAL ENGINEERING, age 38, Ph.D. 15 years teaching and industrial experience, research, publications, desires challenging position in education or industry. Box 137.

ELECTRICAL ENGINEER, B.S.E.E., 30. Six years experience in process engineering for chemical process plant. Desire responsible position in process engineering, design and development or maintenance engineering. Prefer Southeastern location but will consider others. Box 139.

TEACHING OR ENGINEER POSITION in a foreign country. BSEE, MSEE, mathmatics. Experiences include teaching, research and industrial design in computer, control. Resume at request. Box 141.

ELECTRICAL OPERATIONS. BSEE, 43. Past ten years responsible administrative and functional supervision of system, load, plant, and interconnected operation. Other experience coordinator and starting supervisor, and manufacturer's representative-Sales. $10,000. Box 142.

MSEE, former assistant professor of electrical engineering with R and D experience in control systems and computers, desires to return permanently to teaching, with an opportunity to complete doctorate work. Location—south, southeast, or southwest. Box 143.

SPECIAL ADVERTISEMENT

WANTED—comprehensive electrical library by manufacturer. Will purchase intact. Reply giving contents, price and location for inspection. Box 135.

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1959 NATIONAL TELEMETERING CONFERENCE

MAY 1959

The 40 papers included in publication T-115 were presented at the National Telemetering Conference held in Denver, Colo., May 24-27, 1959.

Sponsored by the AIEE, the Instrument Society of America, the American Rocket Society, and the Institute of Aeronautical Sciences, the theme of the 1959 Conference was "Investigation of Space."

Cost of the 411-page publication is $6.50.

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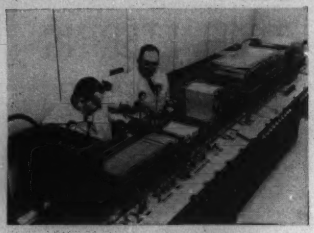
(Continued from page 46A)

IBM
Yorktown, N. Y. . .

A new research program to improve the manufacture of paper through the use of computer control is under way at the company's new research center



at Yorktown, N.Y. IBM scientists concerned with both the paper and ink and control systems fields are combining their efforts in the project, in which a number of paper companies and manufacturers of paper machines are co-operating. An experimental Fourdrinier paper machine, a scale-model of ones used in paper mills, has been installed in the research center. Aim of the program is to regulate and control the Fourdrinier machine to produce uniformly high quality paper. Paper is the most economical material for the familiar IBM cards. However, there are certain physical properties of paper that sometimes cause problems in data processing. Paper normally expands if it is subjected to high temperatures and/or humidity. Accurate computer print-out depends on the precise alignment of the columns. In order to develop a paper with uniform predictable properties, papermaking must become a more practical science through use of a computer to control its many inherent variables.

Servomechanisms, Inc.
El Segundo, Calif. . .

The Redstone Missile that launched Comdr. Alan B. Shepard, Jr. into space from Cape Canaveral was loaded with liquid oxygen (LOX) through the use of Servomechanism's LOX Tanking Computer and once launched an SM/I Thrust Control System maintained the thrust level of the liquid propellant rocket engine at the specified magnitude. SM/I's (LOX) Tanking System, SM/I Type TMC 602, accurately measures, controls and indicates the level of liquid oxygen in the missile tanks. The entire computer is encased in a protective cover, which is designed to withstand the extreme conditions generated by the missile firing. The TMC 602 is the main building block in the process of obtaining a completely automatic propellant loading system.

Walter Kidde & Co., Inc.
New York, N. Y. . .

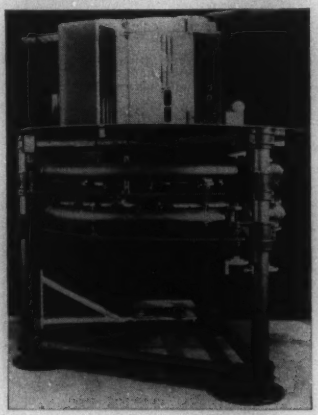
Formation of the Kidde Electronics Laboratories by Walter Kidde & Company, Inc., was announced recently. The laboratories, combining the electronics research and development activities of the parent company, are active in the fields of thermistors, power supplies, static relays, and contactors, and the development of new electronic products for commercial, aircraft, and missile applications, and special ground handling equipment.

Autonetics
Downey, Calif. . .

Ground-breaking for Autonetics' $2 million research center for study and experimentation in advanced microelectronics took place recently on the North American Aviation division's property in the east part of Anaheim (Calif.). By year's end 200 persons—chiefly scientists and engineers—will be employed at the center. The 60,000-square-foot building will be dedicated to advancing technology in electronics and electromechanics in three areas: physical, systems, and components.

Arthur D. Little, Inc.
Cambridge, Mass. . .

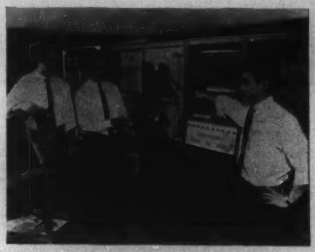
Rubies, sapphires, and silicon carbide crystals needed for advanced electronic devices will be grown in a new, multipurpose, high-intensity, arc imaging furnace. Developed by Air Force-Cambridge Research Laboratory in Bedford, Mass., and Arthur D. Little, Inc., this "clam shell" furnace uses



two opposing concave mirrors to capture radiant energy from an electric arc and focus it into an area ½ inch in diameter to create temperatures in excess of 3,500 Kelvin (6,700 F).

Digitronics Corp.
Albertson, N. Y. . .

Two electronic converters, designed to accommodate the Japanese as well as the English language, have been sold by the Digitronics Corp. to Remington Rand International, for use in



Japan. The converters, which are solid-state and bi-directional, are the first of their kind ever to be used in Japan. Normally, converters provide for an alphabet of 26 characters. To handle data in both English and Japanese, this equipment is capable of providing 96 characters. The converters will be used to convert data from perforated paper tape to magnetic tape, and from magnetic tape to paper tape, at high speed in both directions.

English Electric
West Burton, England . . .

Four 500-mw single-line turbo alternators are to be built for a new power plant in Britain which, at 2,000 mw, are said to have a higher over-all capacity than any station now in operation or under construction anywhere in the world. The new $40 million plant, which will supply enough electricity to meet the needs of a city of more than 2 million people, will be sited at West Burton in the Trent Valley. The first generating unit will come into operation in 1965 and the plant should be fully commissioned by the end of 1967.

Westinghouse Electric Corp.
Pittsburgh, Pa. . .

The Westinghouse Electric Corporation will build two 330,000-kw turbine-generator units for the Pacific Gas and Electric Company's (PG&E) plant at Morro Bay, Calif. They are part of a project which will triple the electric generating capacity of that power plant. Construction has been started on the first turbine-generator, with completion scheduled for 1962. The second unit is scheduled for delivery in 1963. PG&E calculates that the enlarged Morro Bay plant will produce 5 billion kw-hr a year.